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OCTOBER 2013

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FROM THE EDITOR

BY DAVID J. EICHER

Comet West (C/1975 V1) photographed in the spring of 1976. ESO

My first Great Comet

We've now reached the month in which Comet ISON (C/2012 S1) will really start to brighten, presumably becoming a naked-eye object by month's end. It seems like a good time to look back on the first Great Comet I ever saw, Comet West (C/1975 V1).

Danish astronomer Richard M. West found a fuzzy object November 5, 1975, at the European Southern Observatory's facility in La Silla, Chile. West (pronounced "vest") saw an object he described as between 14th and 15th magnitude and with a slight coma 2 to 3 arcminutes in diameter.

When Brian Marsden at the Central Bureau for Astronomical Telegrams received word of the discovery and calculated an orbit, he found that the comet would become bright by February 1976. So was announced Comet West (C/1975 V1).

The comet brightened rapidly as it neared Earth and the Sun. On November 25, 1975, Leo Boethin, living in the Philippines, became the first to spot West visually, glowing faintly at magnitude 12.7 and with a tail measuring just 4 arcminutes long. On December 1, Comet West became visible to Northern Hemisphere observers, and Tsutomu Seki, at the Geisei Observatory in Japan, estimated the magnitude at 12.5. Comet West's appearance became very bright in February 1976, when the comet brightened to 4th magnitude by mid-month and then dramatically grew more brilliant during the next two weeks, reaching magnitude –1.5 by February 24. Close to perihelion passage on the 25th, observers spotted Comet West in the daytime sky using binoculars or telescopes.

Following perihelion, the comet became visible to naked-eye viewers once again March 1. Prominent in the early morning sky, Comet West displayed a brilliant nucleus with a reasonably bright inner coma, both of which could be seen well in the twilit sky. The comet's tail stretched only about 2°, but the overall magnitude was impressively bright at about –1. Over the following days, the tail grew, however, to 10° on the 2nd and as much as 30° long by March 8.

On March 4, Comet West made its closest approach to Earth, and the comet was visible to naked-eye observers throughout the month. On March 5, skywatchers armed with telescopes noted that the comet's nucleus appeared to be split into two parts, separated by about 3 arcseconds. Six days later, telescopic viewers saw the nucleus as four distinct components, which were labeled with letters, as is the custom. Components A, B, and D remained gravitationally bound and were visible for months, although component C faded rapidly, disappearing by March 25.

As the nucleus of Comet West split apart, the comet faded. By March 31, it glowed at magnitude 4.7, keeping it a naked-eye object, but the brilliance of the comet was gone. By early April, it stretched 4° long. Late April witnessed Comet West sinking to the naked-eye limit with merely a 1° tail. Yet amateur and professional astronomers continued to observe Comet West with binoculars and telescopes for two more months, with many unusual observations taking place in May and June.

Let's hope that Comet ISON stays together and gives us a tremendous show. It will have been a long time coming.

Yours truly,

David J. Eicher
Editor

Astronomy

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RON MILLER FOR *ASTRONOMY*

ON THE COVER

Kepler 11b is a giant planet four times as massive and twice the size of Earth. Orbiting 10 times closer to its star than Earth's distance from the Sun, we see it from the scorched surface of one of its possible satellites.

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QUANTUM GRAVITY

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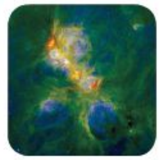
QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

GASSY GALAXY
The Herschel infrared telescope mapped the ionized carbon in the Milky Way's plane and found that 30 percent of our galaxy's molecular gas was hidden.



MINI STARBURST
A study suggests that the Cat's Paw Nebula (NGC 6334) is converting 3,600 Suns of gas into stars every million years, earning it a "starburst" nickname.

DISORDERED DISK
Some scientists say that gaps in disks surrounding young stars may not result from forming planets, but instead from interactions between gas and dust.

SNAPSHOT

Comet ISON begins its big show

After months of waiting, we begin to see whether ISON will be a star.

The wait will soon be over. Comet ISON (C/2012 S1) will shortly brighten to naked-eye visibility. We should soon know just how brilliant this comet is going to be.

Comet fever will then grip the astronomy world when ISON slinks across southern Leo and into Virgo during the first week of November. By then, the comet will brighten to 6th magnitude. ISON then should increase by a magnitude every few days and will dazzle viewers who rise to see it in the early morning hours, perhaps 4 A.M. on into dawn.

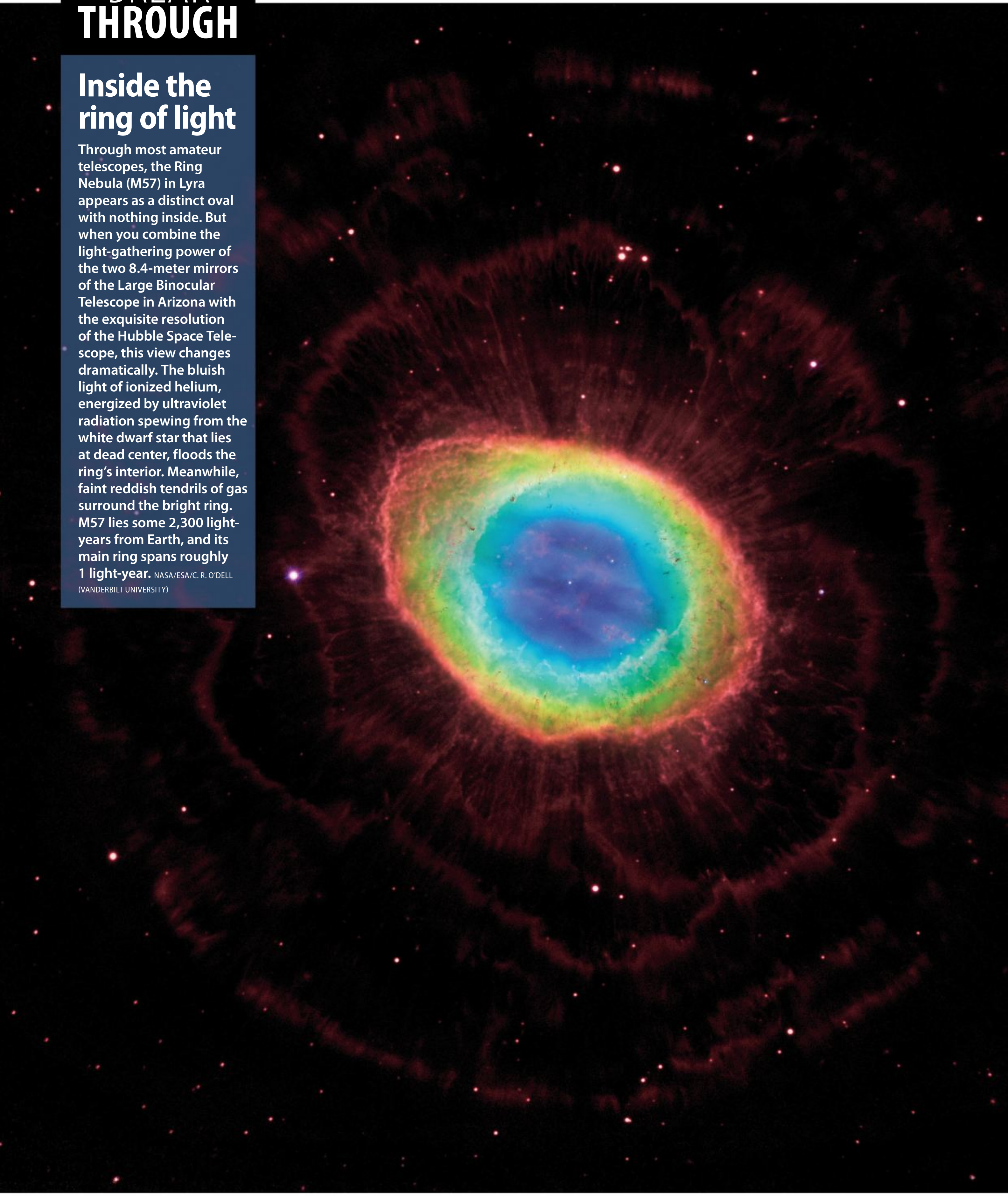
By about November 25, the comet will have become impressively bright, shining at negative magnitudes in eastern Virgo. The 28th brings the comet's perihelion, its closest point to the Sun. ISON may then be as bright as Venus, or as much as 100 times brighter yet. If so, it will outshine everything in the sky save for the Sun and the Moon.
— David J. Eicher

Comet ISON (C/2012 S1) was imaged April 10, 2013, with the Hubble Space Telescope.

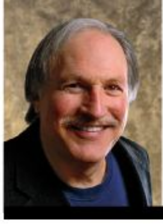
NASA/ESA/J.-Y. LI/THE HUBBLE COMET ISON IMAGING SCIENCE TEAM (COMET ISON); ESA/C. CARREAU (GASSY GALAXY); S. WILLIS (CfA+ISU)/ESA/HERSCHEL/NASA/JPL-CALTECH/SPITZER/CTIO/NOAO/AURA/NSF (MINI STARBURST); NASA GODDARD/W. LYRA (JPL-CALTECH)/M. KUCHNER (GODDARD) (DISORDERED DISK)

BREAK
THROUGH

Inside the ring of light



Through most amateur telescopes, the Ring Nebula (M57) in Lyra appears as a distinct oval with nothing inside. But when you combine the light-gathering power of the two 8.4-meter mirrors of the Large Binocular Telescope in Arizona with the exquisite resolution of the Hubble Space Telescope, this view changes dramatically. The bluish light of ionized helium, energized by ultraviolet radiation spewing from the white dwarf star that lies at dead center, floods the ring's interior. Meanwhile, faint reddish tendrils of gas surround the bright ring. M57 lies some 2,300 light-years from Earth, and its main ring spans roughly 1 light-year. NASA/ESA/C. R. O'DELL (VANDERBILT UNIVERSITY)



STRANGE**UNIVERSE**

BY BOB BERMAN

The vegetarian star

Celebrate one of the sky's most familiar luminaries.

It's been years since the "Strange Universe" column spotlighted a star, any star. How hard is it to choose one from among the 6,000 naked-eye luminaries?

It's a piece of cake. Most stars are dim and cursed with designations like HD 140283 or Zubenelgenubi. Only a handful are brilliant and have popular names. Of them, just one floats directly overhead at this time of year. So it's automatic. Vega (Alpha [α] Lyrae) selects itself.

Of all bright stars, Vega boasts the shortest name — and one of the most familiar. Yet it's routinely mispronounced. That's because few know this phonetics tip: Star names are simple transliterations from their original language. You usually should pronounce them as spelled. Rigel is really RY-jl, Spica is really SPY-kah, and Vega is really VEE-gah. No need to add a Latin twist — even if that's how Jodie Foster bewilderingly said it in the movie *Contact*.

Vega was, until the 19th century, pronounced WEE-gah and even spelled Wega in some antique astronomy books. It derives from Arabic and means "a swooping eagle." It also was an eagle to the ancient Indians and a vulture to the Egyptians. A bird. Don't ever let a friend turn it into a cigar by saying VAY-gah, even if one or two criminally incompetent dictionaries list it that way.

Look overhead just as night falls. From most of the United States, Vega is the only bright star that ascends to within a few degrees of the exact zenith. (It's straight up from the nation's capital.) Shining at a steady magnitude 0, Vega serves as the "standard candle" that the worldwide astronomical community used to calibrate the brightness of everything else in the universe. Like the French bar of platinum once used to define the meter, Vega functions as the sky's reference point for the magnitude system. It's an ideal choice because it displays no flickering or variability, despite years of controversy about this. Moreover, it's a single star like the Sun instead of a binary like so many others.

But it's still not quite a monument to normalcy. In the 1990s, a team of Canadian astronomers announced that Vega, like a fortune-cookie writer, exhibits bizarre peculiarities. It spins crazily in 12 hours, compared to a month for our Sun, despite being nearly three times larger. If it rotated just 18 percent faster, it would break apart.

IN A COSMOS WHERE REDSHIFTS ARE AS COMMON AS TATTOOS, THIS DIAMOND AT THE ZENITH DISPLAYS A BLUESHIFT.

Moreover, its pole of rotation is pointed straight toward Earth, give or take a few degrees. This means that any Vegans (if any organism could ever really live on a star) looking skyward would see our Sun as its north star!

Some 12,000 years from now, we'll return the favor. Vega periodically becomes our pole star as Earth's axis wobbles through its 26-millennium precession. Brightest of all our planet's north stars, it nonetheless misses the celestial stationary point by some 4°. So it never achieves the visual glued-in-place appearance of the current award-winner, Polaris.

Vega has enjoyed more than 15 minutes of fame. It was the first star to be photographed — a feat attained at the exact midpoint of the 19th century, a whopping 163 years ago. It was also the first to have its spectrum taken and, for those who own a star spectroscope, displays a gorgeous mélange of reds, greens, and blues in equal amounts, crossed by prominent dark Balmer lines of hydrogen. Floating a mere 25 light-years from us, Vega is a heavyweight with more than twice our Sun's mass and 36 times its luminosity.

Members of a major vegetarian subculture call themselves vegans, but no one knows if the cuisine on Vega is truly meatless. In any case, vegan ancestors likely did not hail from there. Despite being encircled by a dusty disk with a strong infrared signature that some astronomers have interpreted as evidence of a planetary system, actual life is implausible because of the star's youth, less than one-tenth the age of Earth and our Sun.

As if this weren't enough to keep us interested, Vega marks the approximate direction we travel toward in space. As our entire starry neighborhood participates in the Milky Way's grand rotation, we do a little 9-mile-per-second (14 km/s) sideslip in Vega's general direction. In a cosmos where redshifts are as common as tattoos, this diamond at the zenith displays a blueshift. It's heading our way.

So enjoy nightfall's overhead chess game as this season's brightest stars zoom off in different directions. As the centuries pass, orange Arcturus in the west will totally vanish from sight while Vega grows ever brighter. Some 200 millennia hence, it will enrapture our descendants as the sky's most brilliant star. Celebrated even more than it is today, Vega will retain that honor for the next quarter-million years.

Contact me about my strange universe by visiting **http://skymanbob.com.**

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

FROM OUR INBOX

Earning respect

I have never written a letter to a magazine editor before, but after reading "The life and times of Al Nagler" by Michael E. Bakich (April 2013), I felt compelled to do so.

Recently, I had called Tele Vue Optics customer service regarding the cleaning and inspection of my 2.5mm Nagler eyepiece after a neighbor had inadvertently pressed his eye into it. I began by telling the story to a Tele Vue representative about the exceptional seeing that night that drew a crowd and led to the "incident." Al must have been close by and was intrigued by the story. After some 20 or 30 minutes of speaking with him, I felt as though I was one of his friends. It was an experience I will never forget. He not only received my repeat business, but he also earned my respect. — **Brian Howe,** Petersburg, Pennsylvania

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

CONKED COLOSSUS. The supermassive black hole in NGC 253 seems to have fallen asleep in the past decade even though the galaxy is actively forming stars, say astronomers in the July 10 issue of *The Astrophysical Journal*.

SIZE SHIFT. According to new observations, scientists may have underestimated the girth of the stars in the Kepler field. This change means planets like Kepler 62f, which scientists thought was just 40 percent larger than Earth, are even bigger. NASA/AMES/JPL-CALTECH

EXOPLANETS UNDERESTIMATED?

The recently disabled Kepler telescope has revolutionized exoplanet science. However, a new study may change conclusions scientists make from Kepler's observations because it suggests the stars — and thus the planets — are larger than previously thought, according to a presentation June 4 at the 222nd meeting of the American Astronomical Society in Indianapolis.

Astronomers used the Kitt Peak National Observatory Mayall 4-Meter Telescope in Arizona to gather spectra from a subset of Kepler's stars. Spectra show light divided into its component wavelengths, telling scientists about not just brightness but also composition, temperature, and size.

"Most of the stars we observed are slightly larger than previously thought, and one-quarter of them are at least 35 percent larger," says lead scientist Mark Everett of the National Optical Astronomy Observatory. "Any planets orbiting these stars must be larger and hotter as well."

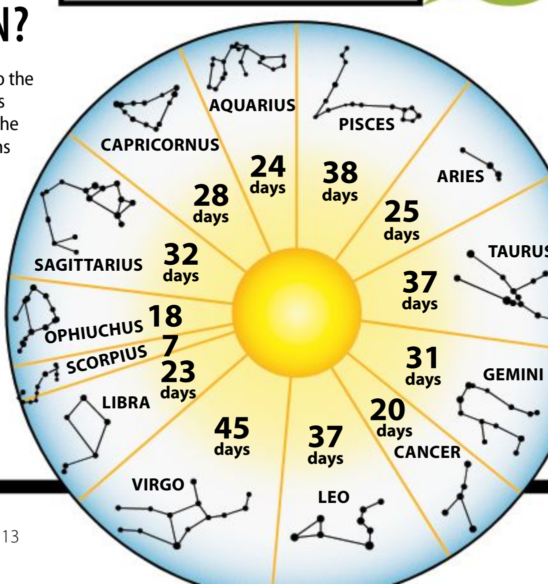
Kepler watches for the telltale dip in a star's brightness that means a planet may be passing in front and blocking some of its light, and astronomers use the specifics of this transit to peg the planet's size. If the size of the star is incorrect, the calculated size of the planet will be, too. According to the new results, Kepler's fruits may need to be re-peeled. "These new results reduce the number of candidate Earth-size planet analogs," continues Everett.

Although scientists might not have come as close to finding an Earth-like planet as they thought, the more data they combine, the smaller the planets they can find. Fattening up the stars simply means that astronomers may have to searcher harder and longer. Luckily for them, half of Kepler's observations remain untouched on discs. — **Sarah Scoles**

HOW LONG IS THE SUN IN THAT CONSTELLATION?

FAST FACT

Virgo is the largest zodiacal constellation and the second-largest star pattern overall. Only Hydra is larger (by 0.6 percent).



SIGN OF THE TIMES. According to the traditional horoscope, the Sun spends either 30 or 31 days in each "sign" of the zodiac. But astrologers based the signs on the constellations that surround the Sun's path through the stars. The actual time the Sun spends in each of those star patterns varies greatly. And notice the "extra" constellation astrologers have never taken into account — Ophiuchus the Serpent-bearer. The Sun spends 18 days traveling through it compared to only seven in Scorpius. *ASTRONOMY*: MICHAEL E. BAKICH AND ROEN KELLY

BRIEFCASE

ON THE REBOUND

Some of the light from Supernova 2009ig, the brightest of that year, bounced off material surrounding the exploded star, suggesting the star broke apart because a companion donated too much mass. The scattered radiation arrived at Earth the year after scientists observed the initial detonation, showing up as a delayed "light echo," the research team reported June 6 at the 222nd American Astronomical Society conference in Indianapolis.

BOOMING BLACK HOLES

Black holes are responsible for 20 percent of the cosmic infrared background — light from a time when structure first emerged from cosmic soup — says a study in the May 20 issue of *The Astrophysical Journal*. Astronomers compared X-ray maps to infrared maps to find these early black holes, the only objects that appear as "hot spots" on both.

DISTANCE DETERMINATION

Scientists pinned down the distance to a pulsar 30 percent more accurately than their previous record. Using the Very Long Baseline Array, they measured the object's parallax — how its position changed relative to background objects as Earth moved in its orbit. With precise measurements like this one, reported in the June 20 issue of *The Astrophysical Journal*, scientists will be better able to characterize gravitational waves. — **S. S.**

25 years ago in *Astronomy*

In the October 1988 issue of *Astronomy*, Gerrit L. Verschuur penned "Will Solar Max be Saved?" about a Sun-observing space telescope. The Solar Maximum Mission's (SMM) orbit would take it crashing back to Earth in December of that year without intervention.

Verschuur argued for saving the craft, which was the only observatory of its kind at the time: "A decision at the highest level is required to allocate the $25 million for a shuttle mission to prolong the lifetime of a spacecraft." Unfortunately, SMM fell out of its orbit "in a shower of flaming metal" at the end of the year.

10 years ago in *Astronomy*

In the October 2003 issue, Michael Carroll bid farewell to another scientific spacecraft in "The long goodbye." The ailing Galileo had studied the Jupiter system and was on a collision course with the planet.

"Galileo has weathered a host of hardware and natural obstacles," wrote Carroll. Project manager Eilene Theilig said, "There is sadness for the final farewell, but at the same time, there's a sense of celebration for what the mission and project have done." Currently, NASA's Juno spacecraft is on its way to the largest planet; it will be the first to visit since Galileo's violent departure. — **S. S.**

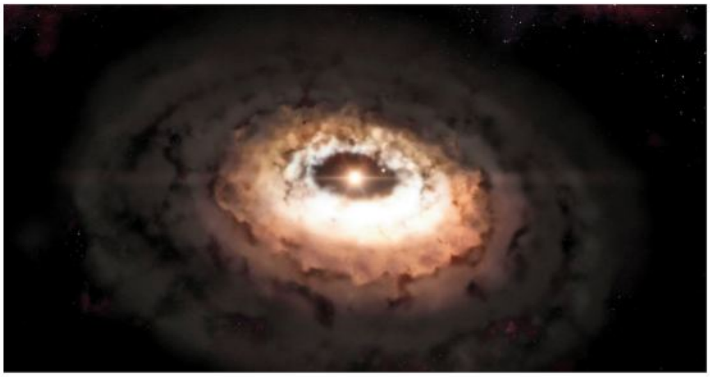
DELICATE DWARF. According to a June 10 report in *The Astrophysical Journal*, Segue 2 has a mass 150,000 times that of the Sun — that's nearly 10 million times lighter than the Milky Way and makes the galaxy the least massive one yet measured.

ALMA images possible missing link

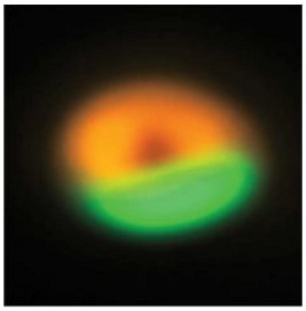
Scientists have struggled to piece together planet formation — how dust particles just millionths of a meter across eventually grow to worlds thousands of kilometers wide. Simulations show that particles can collide with others and break apart or spiral into their star and thus never get big enough. But a new observation of the young star system Ophiuchus IRS 48, some 390 light-years from Earth, may shed light on the complicated process of planet formation.

A disk of evenly distributed gas and small dust grains — each about 50 millionths of a meter — surrounds the star; this disk also contains a thick gap where scientist think a 10-Jupiter-mass planet might be forming and clearing a path. But when they used the Atacama Large Millimeter/submillimeter Array (ALMA) to look at larger dust grains, they found a crescent-shaped region of millimeter-sized grains that extends about one-third of the way around the star. This area lies between 45 and 80 astronomical units (1 astronomical unit equals the average distance between Earth and the Sun) from Oph IRS 48.

The team, led by Nienke van der Marel of Leiden Observatory in the Netherlands, suggests in the June 7 issue of *Science* that this newly imaged area is actually a dust trap — a cavity where turbulence from the planet can collect and grow the larger dust grains. Given the region's distance from its star, the scientists think it may be a holding compartment for future comets. — **Liz Kruesi**



FORMING ROCKS. The young star Ophiuchus IRS 48 has a surrounding disk of gas and dust, but larger dust particles appear to congregate in a region extending only about one-third of the way around the star's lower portion, as shown in this artist's illustration. ESO/L. CALÇADA



ALMA (ESO/NAOJ/NRAO)/NIENKE VAN DER MAREL

DUST TRAP. Observations suggest the ring of material around Ophiuchus IRS 48 has a "holding cavity" for larger, millimeter-sized dust particles (green), whereas finer, micron-sized dust particles circle the entire star.

Swift takes glamour shots of the Magellanic Clouds

NASA/SWIFT/S. IMMLER (GODDARD) AND M. SIEGEL (PENN STATE)

CLOUDY SKIES. You've never seen the Large Magellanic Cloud (LMC), a satellite galaxy of the Milky Way, quite like this. This 160-megapixel image shows ultraviolet (UV) light from nearly 1 million separate objects. Astronomers at NASA and Pennsylvania State University in University Park used the Swift space telescope to map the high-energy radiation that comes from high-powered, hot stars and star-forming regions in the LMC and the Small Magellanic Cloud, which boasted its own 250,000 UV sources. Scientists stitched thousands of images together to make glamour shots of both galaxies, which NASA released June 3. — **S. S.**

QUICK TAKES

SUCCESSFUL SUPERNOVA

Scientists from the Max Planck Institute for Astrophysics completed the most complex 3-D simulations to date of how supernovae explode and produce neutron stars. Their study appeared in the June 10 issue of *The Astrophysical Journal*.

TRIUMPHANT SCOPE

Scientists announced June 4 at the American Astronomical Society meeting in Indianapolis the discovery of a Saturn-sized gas-giant exoplanet, KELT-6b, some 700 light-years away using a 1.6-inch-wide (4.2 centimeters) automatic telescope.

TMT FUNDING

The Japanese parliament passed a 2013 budget May 15 with 1,244 million yen (approximately $12.2 million U.S.) to contribute to the proposed Thirty Meter Telescope (TMT).

GOODNIGHT, GALEX

NASA decommissioned its Galaxy Evolution Explorer (GALEX) at 12:09 P.M. PDT June 28 after a decade of observing the ultraviolet universe.

SOLAR STUDY

The balloon-borne solar experiment Sunrise II lifted off June 12 for its journey lasting five days and seven hours. It traveled around the North Pole at an altitude of 22 miles (35 kilometers).

WEIGHTY WHITE DWARF

Astronomers report in the July 1 issue of *The Astrophysical Journal Letters* their observation of pulsations from the most massive white dwarf star found to date, GD 518, with a mass 1.2 times our Sun's.

SPYING THE SUN

On June 27, NASA launched its Interface Region Imaging Spectrograph to learn how the Sun's material moves, gathers energy, and heats up as it travels through the solar atmosphere and into the Sun's wind.

ACTIVE CENTER

Astronomers found dust above and below the doughnut-shaped structure expected to surround galaxy NGC 3783's central supermassive black hole. They suggest in the July 10 issue of *The Astrophysical Journal* that the black hole's wind blows away dust. — **L. K.**

SECRET**SKY**

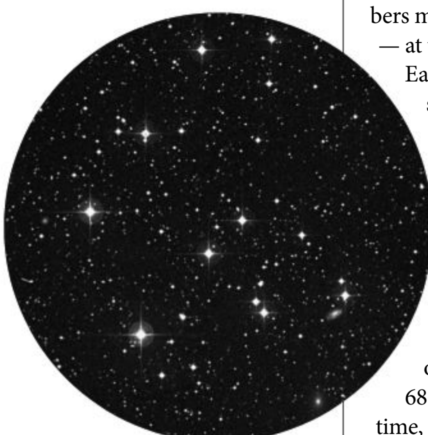
BY STEPHEN JAMES O'MEARA

Stellar surprises

When you go guideless into the night sky, you never know what you'll find.

A computer-guided go-to telescope is a great timesaver, especially when you want to take full advantage of a clear night. Still, every now and then it's good to turn the telescope's intelligence center off and your eyes' alert system on. Then, with nothing but your eye and the sails of your mind wide open, pick a course in the sky and start scanning. When you explore the celestial landscape without an agenda, visual surprises are bound to occur.

Several such unplanned sweeps of the sky with binoculars and a telescope led to my independent discoveries of some fascinating asterisms — patterns of stars smaller than constellations — and star clusters. An advanced amateur astronomer in São Paulo, Brazil, though, had preempted all of my finds. Bruno Alessi discovered some 40 such stellar groupings between 1997 and 1998 and published them as part of a catalog in *Astronomy & Astrophysics* in 2002. Here, I describe three of my favorite Alessi objects. I hope you, too, will explore the sky and experience the joy of stumbling upon interesting stellar arrangements on your own.



The bright central stars in this image make up Alessi J20046–1030, located between Capricornus and Aquila. They may be the same distance from Earth and physically related. The image shows a region 20' across. SLOAN DIGITAL SKY SURVEY

Alessi J20046-1030

I first encountered this curious knot of stars October 16, 2006. At the time, I was using 10x50 binoculars to casually sweep the boundary between northwest Capricornus and southeast Aquila. When I got to a point about 4° northwest of the beautiful double star Alpha (α) Capricorni, I noticed a 20'-wide glow just over the border into Aquila. When I used averted vision, the glow splintered into little sparks of light. Through a 4-inch scope at 23x, the roughly magnitude 7.5 glow resolved into about 20 stars, the brightest of which is magnitude 8.8. Alessi's research has shown that, based on proper motions of these stars, the members may be physically related — at the same distance from Earth and not simply in the same direction in the sky.

Alessi J20053+4732

I found this beautiful object September 10, 2009, while waiting for patches of clouds to move away from the open star cluster NGC 6811 in Cygnus. To pass the time, I trained my 5-inch telescope at 33x onto the twin golden stars Omicron (ο) Cygni. Because the Milky Way field around these stars is rich, I decided to center them and then sweep west.

To my surprise, a curious gathering of about two dozen irregularly bright stars (from 9th to 11th magnitude), packed in an area no larger than 10' across, suddenly entered the field of view. When I bumped the power up to 66x, I counted more than 40 stars between 9th and 12th magnitude in an area 12' across.

I found no identifiable clusters at this position on my charts, but Alessi had discovered this asterism more than a decade before. To my knowledge, this group, though cluster-like, is an asterism of unrelated suns that are different distances from Earth.

The asterism Alessi J20053+4732, made of 40 stars between 9th and 12th magnitude, is pictured in this 15'-wide image. SLOAN DIGITAL SKY SURVEY

Alessi J23407+0757 resembles a third dipper in the sky. The image is roughly 15' across. SLOAN DIGITAL SKY SURVEY

Alessi J23407+0757

I chanced upon this pretty gathering of reasonably bright stars January 20, 2003, while looking for Comet NEAT (C/2002 V1). The binocular view revealed a large and "diffuse" object 2¼° north of Iota (ι) Piscium, in the famous Circlet of Pisces, and 1½° south of the comet.

Through a 4-inch scope, I estimated the object's brightness to be magnitude 5.8 and resolved it into a lovely gathering of nine stars shining between 8th and 11th magnitude in an area 15' across. This quaint grouping forms what I call the Little Ladle, the kind you use to scoop hot fudge for an ice-cream sundae.

Now it's your turn. Take a look at these three objects, and then set out and try to find your own. The night sky has many more of them left to be discovered. Send your results to someara@interpac.net.

FROM OUR INBOX

A perfect remembrance

My thanks to author Raymond Shubinski and *Astronomy*'s David J. Eicher and Michael E. Bakich for their loving tribute to *Cosmos* and my late husband, Carl Sagan (in the July 2013 issue). I savored every word. Ray's retrospective told the *Cosmos* story with that rare combination of accuracy and passion. Dave's recollections of Carl and his humanity mean so much to me. Every word rang true. He really captured who Carl was and what *Cosmos* is about.

I'm writing from Santa Fe, New Mexico, where we are just finishing up a month of location and studio shooting for the new *Cosmos* before we travel on to Europe and elsewhere. I wanted you to know that the scores of people working on this new series, including me, share an overarching goal: to be deemed worthy of the original and to reflect well on Carl's magnificent legacy.

Thanking you from my heart. — **Ann Druyan,** co-creator of *Cosmos*

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

ASTRO**NEWS**

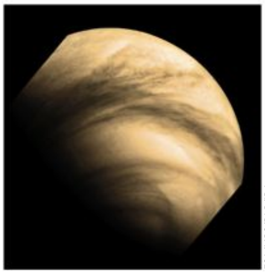
FAST FACT

Earth orbits the Sun at an average speed of 66,616 mph (107,208 km/h).

Venus winds speed up

It seems that the more scientists learn about Venus, the more questions they have. One of the many aspects of our sister planet shrouded in mystery is the super-rotation of its atmosphere, which causes winds to circle Venus in four Earth days. And recent analysis has shown that these wind speeds don't stay consistent; two complimentary studies — one by a Japanese-led team published in the January *Journal of Geophysical Research-Planets* and one by a Russian-led team published in the September–October *Icarus* — have revealed that these winds vary regularly and are ultimately speeding up.

Using the Venus Monitoring Camera aboard the European Space Agency's (ESA) Venus Express spacecraft, the teams were able to track the movements of distinct features in the clouds and therefore determine their velocities. When the orbiter arrived in 2006, scientists learned that wind speeds at low latitudes averaged about 190 mph (300 km/h). Over the course of the mission, the velocities increased to some 250 mph (400 km/h).



ESA/MPS/DLR/IDA

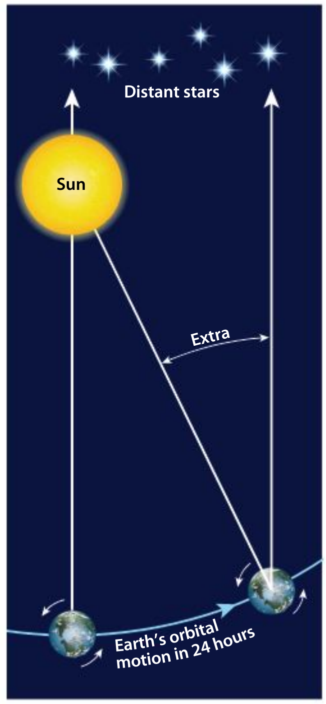
SUPER SPEEDS. By studying cloud features captured by the Venus Monitoring Camera on the Venus Express spacecraft, scientists have discovered that the planet's wind speeds have increased in the past six years.

"Such a large variation has never before been observed on Venus," says coauthor Igor Khatuntsev of the Space Research Institute in Moscow, "and we do not yet understand why this occurred."

In addition to this long-term increase, the teams observed localized short-term variations.

"Further investigations are needed in order to explain what drives the atmospheric circulation patterns that are responsible [for the global wind speed increase] and to explain the changes seen in localized areas on shorter timescales," says Håkan Svedhem, ESA's Venus Express project scientist. — **Karri Ferron**

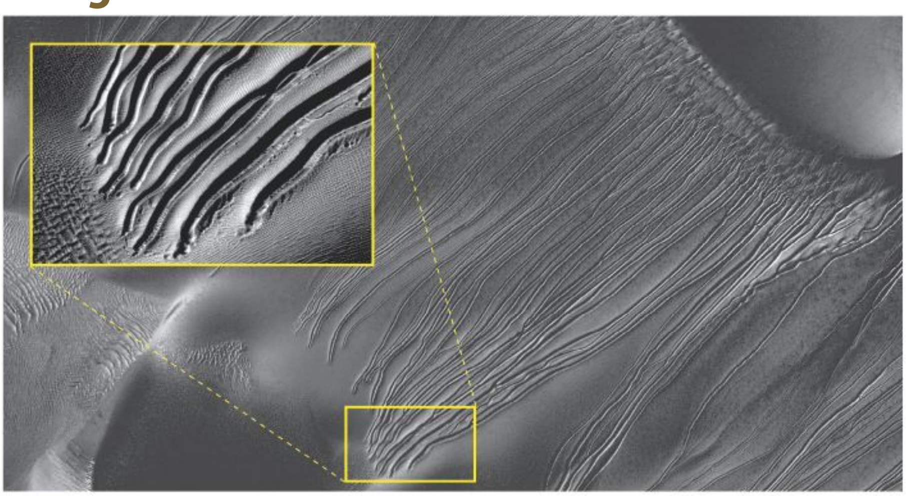
WHAT A DIFFERENCE A DAY MAKES



ASTRONOMY: MICHAEL E. BAKICH AND ROEN KELLY

EXTRA TIME? A solar day is slightly longer than a sidereal day because Earth is not stationary. As it orbits the Sun, our planet must rotate the extra amount shown for the Sun to return to the position it held in the sky the previous day.

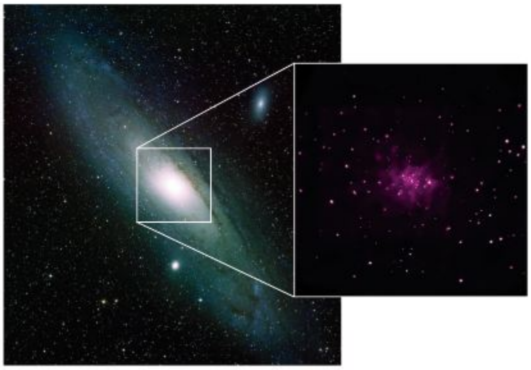
Are gullies on Mars from ice blocks?



NASA/JPL-CALTECH/UNIV. OF ARIZONA

SURFING MARS. The High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter spied these "linear gullies" on the side of a large sand dune in Russell Crater. A team of scientists suggests these few-meters-wide grooves result from chunks of frozen carbon dioxide, also known as dry ice, sliding down the sand. After the block stops at the base of the dune and sublimates to gas, it would leave behind the "pit" marks seen in the close-up image. This research appeared in the July issue of *Icarus*. — **L. K.**

SPACE COLLABORATION. NASA Administrator Charles Bolden signed an agreement of cooperation with Italian Space Agency President Enrico Saggese to participate with the European and Japanese BepiColombo mission to Mercury.



NOAO/AURA/NSF (OPTICAL); NASA/CXC/SAO/BARNARD, ET AL. (X-RAY INSET)

HEAVILY POPULATED. Scientists using NASA's Chandra X-ray Observatory found 26 new black holes in the Andromeda Galaxy (M31).

Chandra spies black holes

NASA's Chandra X-ray Observatory spied on our next-door neighbor, the Andromeda Galaxy (M31), and found 26 new black holes. These objects, which add to nine already found, are the infinitely dense remains of dead massive stars.

Astronomers combined 150 observations to find the X-ray fingerprints that uniquely identify these objects, a study they published June 20 in *The Astrophysical Journal*.

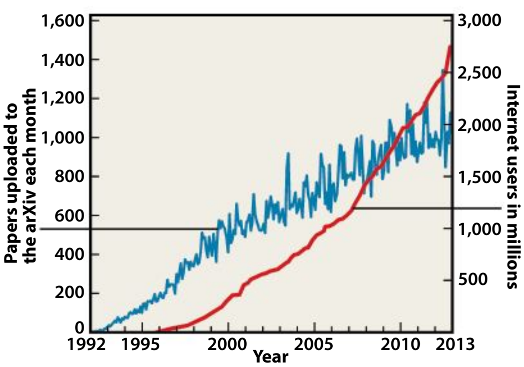
Seven of the new objects are within 1,000 light-years of their big brother — the supermassive black hole at M31's center — more than scientists have found that close to our own black hole.

With 35 known black holes, Andromeda has the most scientists have found in any galaxy outside the Milky Way. Although that abundance is partly because M31 is nearby and easier to see, this galaxy also has a larger bulge around its center than some, like the Milky Way, explaining why its central neighborhood is more crowded than ours. **— S. S.**

FAST FACT

Nearly 2 million scientific papers were published in 2012.

THE RISE IN OPEN-ACCESS (UNOFFICIAL) PUBLISHING

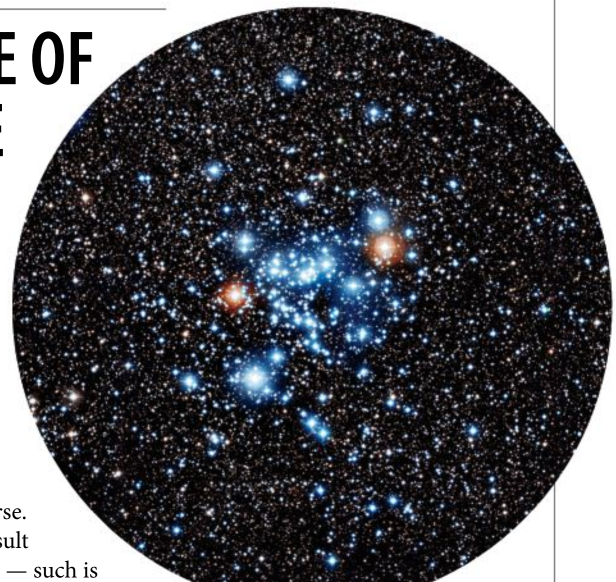


DIGITAL DATA. Normally, to read a scientific article, you have to purchase an expensive journal subscription, unless you work at an institution that has one. To encourage collaboration and get scientific results out quickly, astronomers began placing their articles on a free website called the arXiv in 1992. While that year only a few people uploaded papers, thousands of scientists currently put their work out there each month. The accessibility of articles has risen with the number of Internet users who are hungry for scientific information.

ASTRONOMY: SARAH SCOLES AND ROEN KELLY, AFTER ARXIV AND INTERNET WORLD STATS

SPACE SCIENCE UPDATE

NEW TYPE OF VARIABLE STAR FOUND



RESTLESS RESIDENTS. After analyzing seven years of observations of star cluster NGC 3766, astronomers identified a new class of variable stars that pulsate with periods of a few hours. ESO

Astronomers have cataloged some 48,000 variable stars — those whose brightnesses vary — and these objects can tell them a tremendous amount about the universe. Such fluctuations can result from a surface explosion — such is the case with a nova — or changes deep within a star's core that cause the sun to fluctuate in size and therefore luminosity. Researchers learn a lot about stars, such as their rotations and their internal compositions, by studying stellar variability.

Scientists group those stars that vary due to intrinsic characteristics according to their age, brightness, and color (or temperature). Often, these luminosity fluctuations correspond to the specific stellar evolution phase those stars are in. But astronomers announced that they have identified a new group of variable stars that shouldn't exist according to stellar evolution models. They describe their observations in the June issue of *Astronomy & Astrophysics*.

The team of researchers from Geneva Observatory in Switzerland studied star cluster NGC 3766, which lies some 6,500 light-years from the Sun and is about 20 million years old. Open star clusters hold hundreds to thousands of stars that were born together and therefore evolve together. Astronomers thus study these objects to learn about stellar evolution.

Nami Mowlavi and colleagues observed NGC 3766 and 26 other open clusters several times each year from 2002 through 2009 for 10 to 15 nights at a time. For all observations, they used the 1.2-meter Leonhard Euler Telescope at La Silla, Chile.

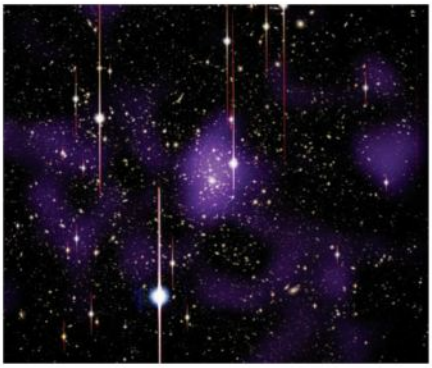
In total, they captured 3,551 images of NGC 3766 and studied its brightest 3,547 stellar members looking for pulsations. They then separated out five groups of variable stars, and one of those is a new classification.

The team says this new, as-yet-unnamed group has 36 members. All of the stars are in the main sequence phase of stellar evolution, meaning they are fusing hydrogen to produce helium and energy within their cores, and are hot A- and B-type stars. (Such stars are more massive than the Sun.) They have pulsation periods between 0.1 and 1.1 days, and 32 are in a narrower range of 0.1 to 0.7 day. The astronomers noted that the stars with longer pulsation periods also have larger brightness differences, although all 36 stellar members' brightnesses varied by just 1 to 4 thousandths of a magnitude, or between 0.1 and 0.6 percent. The pulsation periods also remained stable over the seven years of observations. One-third of the new group's members appear to pulsate in multiple frequencies.

Mowlavi and colleagues recommend that astronomers search other open star clusters for more members of this new class, which they propose be named "low amplitude periodic (or pulsating) A and late-B variables." **— L. K.**

FAST FACT

Scientists first discovered hints of dark matter in the 1930s. Fritz Zwicky noted that galaxies in the Coma cluster were moving so fast that the cluster must contain invisible mass.



NAOJ/ASIAA/SCHOOL OF PHYSICS AND ASTRONOMY, UNIVERSITY OF BIRMINGHAM/KAVLI IPMU/ASTRONOMICAL INSTITUTE, TOHOKU UNIVERSITY

DARK DENSITY. Astronomers measured the slight warping of background light due to the mass of 50 foreground galaxy clusters and reconstructed the dark matter distribution (shown in purple) of those galaxy clusters to find that its density agrees with the leading theory.

More evidence for cold dark matter

By observing 50 galaxy clusters that existed between 2.0 and 3.6 billion years ago, astronomers have found further evidence to support the leading theory of dark matter's secret identity. This material makes up some 85 percent of the universe's mass, but it doesn't emit, absorb, or reflect radiation, so studying it is difficult. Galaxy clusters, some of the largest structures in the universe, hold large reservoirs of dark matter and thus make ideal cosmic laboratories to study this mass.

One way to learn more about dark matter is by utilizing a consequence of Albert Einstein's general theory of relativity: Objects with mass warp space-time. So, by studying how a massive structure — like a galaxy cluster — bends the light from background objects, scientists can learn about dark matter's properties. Researchers using the Subaru Telescope atop Mauna Kea in Hawaii studied this "weak gravitational lensing" resulting from 50 galaxy clusters to determine how their densities change from their centers to edges.

They found that the density profiles match that expected if dark matter is "cold," meaning the particles move slower than light-speed and therefore can stick together to form larger and larger structures. Most astronomers believe the universe's invisible matter is cold, and this new study, which appeared in the June 1 issue of *The Astrophysical Journal Letters*, lends support to the theory. — **L. K.**

503

The number of new extrasolar planet candidates found by the Kepler telescope and announced June 7 by the mission's team.

OBSERVING**BASICS**
BY GLENN CHAPLE

Heavenly sketches

Drawings of astronomical objects reveal what you'll really see through the eyepiece.

Take a few minutes to flip through the pages of this magazine. Time and time again, you'll come across absolutely stunning images. Whether a Hubble Space Telescope mosaic of the Orion Nebula, a portrait of the Andromeda Galaxy taken from a major observatory, or an amateur astronomer's photo of the Horsehead Nebula, such masterpieces inspire us to venture out for a firsthand telescopic view.

And therein lies the problem, especially where the neophyte backyard astronomer is concerned. The camera captures color and faint detail beyond the grasp of the human eye alone. Unaware of that fact, newbies peer into the eyepiece expecting an observatory's-eye view of the Andromeda Galaxy. Instead, they see nothing more than a grayish, oval-shaped blob. The Orion Nebula doesn't fare much better. The reds and greens that are so vivid in the Hubble photo are absent. And the Horsehead? It's nowhere to be seen!

For depictions of what the Orion Nebula, Andromeda Galaxy, Horsehead Nebula, and other celestial objects *really* look like, you can do no better than refer to an "astrosketch" — in its simplest form, a pencil-and-paper rendering of what the observer sees at the eyepiece.

If you're a regular *Astronomy* reader, you may be familiar with our past astrosketching features. During a three-year run that began in September 2009, Editor David J. Eicher penned the monthly piece "Deep-sky Showcase." It featured deep-sky drawings culled from a logbook he kept over a 36-year span. In January, Eicher passed on the baton to renowned artist Erika Rix, who shares her expertise in the column "Astro Sketching." (You'll find this month's edition on p. 68.) In the January 2012 issue of *Astronomy*, we ran the all-encompassing five-page article "How to sketch deep-sky objects," written by Brandon Doyle. I even tackled "Astrosketching 101" in my March 2010 column. In addition, readers often post sketches to our website; check out the gallery at www.Astronomy.com/sketches.

Sketches like this one of the Orion Nebula (M42) through an 8-inch telescope show observers what they can truly expect to see at the eyepiece. JEREMY PEREZ

The Internet definitely is an invaluable source of astrosketch galleries. One of the best is "Belt of Venus" (www.beltofvenus.net), the creation of graphic artist Jeremy Perez. From there, take a cyber stroll through the websites of Michael Vlasov (www.deepskywatch.com), Mark Portuesi (http://www.jotabout.com/portuesi/astro), Bill Greer (www.rangeweb.net/~sketcher), and Brandon Doyle (http://brandon-doyle.weebly.com).

Want more? You can get a regular dose of astrosketching at the Astronomy Sketch of the Day (ASOD) website (www.asod.info). Besides the "sketch du jour," ASOD offers an archive of hundreds of eyepiece drawings dating back to March 2007.

A common myth about sketching is that it's an activity for accomplished artists only. Not so! Your goal isn't to produce a museum-quality masterpiece. You simply want a pencil-and-paper rendering to place in a logbook for future reference. As with any facet of art, sketching can be learned under the proper guidance.

Several online tutorials will help. Try either of Michael Rosolina's "Astro Sketching Workshop" slideshows (www.slideshare.net/mrosolina) and Martin Lewis' *PowerPoint* presentation (www.skyinspector.co.uk). A pair of sketching how-tos by accomplished astroartist Carol Lakomiak is available via the Royal Astronomical Society of Canada website (www.rasc.ca/astrosketchers-group) — one on sketching the Moon and one on drawing the Sun and deep-space objects.

If you're a visual learner, these video clips will help. Check out Eicher's "Sketching from the telescope" (www.Astronomy.com/sketching) and Perez's "Introduction to Astronomical Sketching" (http://youtu.be/QDC3R39AcSA). Both offer clear step-by-step instructions on sketching deep-sky objects.

Finally, for a complete guide to drawing at the eyepiece, I highly recommend *Astronomical Sketching: A Step-by-Step Introduction* (Springer, 2007). This handbook, part of the Patrick Moore "Practical Astronomy" series, includes sections by Rix and Perez, as well as Richard Handy, David B. Moody, and Sol Robbins. It's on my bookshelf; it should be on yours.

Astrosketching is a fun alternative to astroimaging. It's easier than you might think, it sharpens your visual skills, and it ultimately evolves into a portfolio that will become a valuable lifetime resource. Give it a try!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: the invasion of the green laser! Clear skies!

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Sarah Scoles**

Cold as space — Supernova hot

Pop starship

Justin Bieber buys a ticket on Virgin Galactic's *SpaceShipTwo*. When asked whether he spent $250,000 to impress the ladies, he was like, "Baby, baby, baby, no."

Yuri's night

Oleg Kapanets releases the film *Gagarin: The First in Space*. He has optimism to match the Russian zeitgeist: "A separate movie about Gagarin's death could be made."

Mixed metaphor

The Harvard-Smithsonian Center for Astrophysics says the Cat's Paw Nebula is "littered" with new stars. This starburst is not one whose rainbow you want to taste.

Upward mobility

Our galactic spiral arm is more than just a "spur" of a larger arm. This is the only discovery ever to suggest Earth's place in the universe is not totally bourgeois.

VIRGIN GALACTIC (POP STARSHIP); THINKSTOCK (YURI'S NIGHT); S. WILLIS (CFA, ISU); ESA/HERSCHEL; NASA/JPL-CALTECH/SPITZER; CTIO/NOAO/AURA/NSF (MIXED METAPHOR); NASA/JPL-CALTECH/R. HURT (UPWARD MOBILITY)

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

ASTRONEWS

MARS CHEMICAL. The clay within martian meteorite MIL 090030 contains boron, say scientists in an article published June 6 in *PLOS ONE*.

Exoplanets found in unlikely places

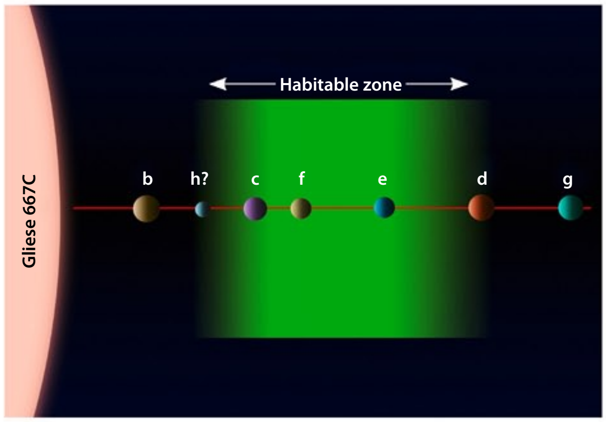
On June 26, two different teams announced surprising exoplanet finds that could increase the number of predicted planets that exist in the Milky Way.

In the first study, which appeared online in *Astronomy & Astrophysics*, astronomers confirmed that a member of a triple-star system, the low-mass sun Gliese 667C, hosts at least six planets, including three that orbit in the star's habitable zone where liquid water could exist. This fully packed area, the first of its kind, is home to three super-Earths, not just one, as previous observations of the star system had indicated.

The discovery is important given the large population of low-mass stars in the Milky Way. "The number of potentially habitable planets in our galaxy is much greater if we can expect to find several of them around each low-mass star," says author Rory Barnes of the University of Washington in Seattle. "Instead of looking at 10 stars to look for a single potentially habitable planet, we now know we can look at just one star and have a high chance of finding several of them."

Another exoplanet first appeared online the same day as the Gliese 667C results, this time in *Nature*, as astronomers announced the first transiting worlds discovered in an open star cluster. The two planets, which are both less than three times the size of Earth, lie some 3,000 light-years away in NGC 6811. Cataloged as Kepler-66b and -67b, these exoplanets were a surprising find considering the frequent gravity tugs and harsh stellar winds that characterize dense star clusters.

"These planets are cosmic extremophiles," says lead author Soren Meibom of the Harvard-Smithsonian Center for Astrophysics in Massachusetts. "Finding them shows that small planets can form and survive for at least a billion years, even in a chaotic and hostile environment." — **K. F.**

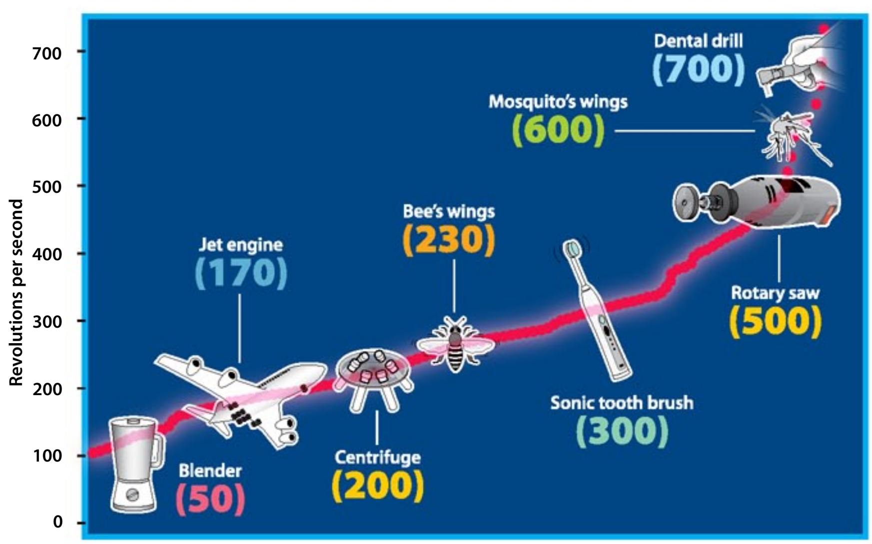


GOLDILOCKS GOLD MINE. After re-examining the planetary system Gliese 667C, which lies 22 light-years away in the constellation Scorpius, scientists confirmed that three super-Earths lie within the host star's habitable zone — a region where liquid water could exist. ESO

WHAT SPINS AS FAST AS A MILLISECOND PULSAR?

FAST FACT

When Jocelyn Bell and Anthony Hewish discovered the first pulsar in 1967, they called it LGM-1 for "little green man 1."



QUICK AND DEAD. Millisecond pulsars are some of the most extreme objects in the universe. They are the remnants of massive stars that were compressed to the size of a city but still have the mass of our Sun, making them approximately as dense as atomic nuclei. They can spin hundreds of times every second. In this plot, the 206 millisecond pulsars in the Australian Telescope National Facility's catalog are compared to more familiar, but much smaller, objects that spin or beat at the same rates. *ASTRONOMY*: SARAH SCOLES AND KELLIE JAEGER

ASTRO**CONFIDENTIAL** BY KARRI FERRON

Scientists' analysis of the T Pyxidis light echoes was based on comparing them to brightness measurements of the white dwarf made by members of the American Association of Variable Star Observers.

WHAT ARE RECURRENT NOVAE TEACHING US ABOUT STELLAR EXPLOSIONS?

Jeno Sokoloski
Associate research scientist at the Columbia Astrophysics Laboratory in New York

Nova explosions occur when hydrogen-rich material on the surface of a white dwarf — the burned-out core of a Sun-like star — accreted from a companion star experiences runaway thermonuclear burning. Because recurrent novae erupt every few decades, we observers can predict their explosions (to some extent!) and therefore catch the early outburst behavior much more reliably than in classical novae, which have only been seen to erupt once. Recurrent novae also provide the opportunity to examine nearly identical eruptions repeatedly.

Such observations have helped us understand why the ejecta from novae are rarely spherical and the impact these explosions have on the binary system. For example, the recurrent nova T Pyxidis erupted in April 2011 for the first time since 1966. Our observations of the light echoes from old debris around the pre-existing remnant using the Hubble Space Telescope indicated that this debris is dominated by an inclined ring of material, presumably along the system's orbital plane, and therefore that the companion star helped shape the outflow.

The distance we derived from the light echoes also confirmed that the companion star in T Pyx loses material to the white dwarf at an extraordinarily high rate, most likely because the luminous eruptions heat it and cause it to expand. Moreover, the change in the orbital period of T Pyx during the most recent outburst showed that it ejected so much mass that its white dwarf is unlikely to ever become massive enough to explode as a type Ia supernova. Whether or not a particular accreting white dwarf erupts as a type Ia supernova, if such high accretion rates can be stimulated by nova eruptions in close binaries and if they can be maintained for even a few decades following an explosion, then novae must strongly impact the evolution of a close binary.

PAUL MARAGAKIS

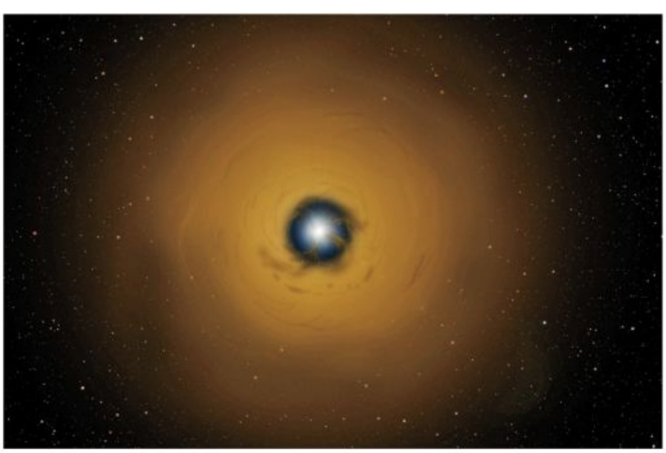
ASTRO**NEWS**

FAR-OUT FORMATION. A gap in the dust disk around TW Hydrae might indicate a planet is forming 80 times the Earth-Sun distance from the star, say scientists in the July 1 issue of *The Astrophysical Journal*.

Young star suggests our Sun was a fitful child

Because astronomers were not around to see the Sun in its younger years, they like to find alien stars at different points in their lives and watch how they grow up. If they find newborn, teenage, and young-adult stars similar to the Sun, they can fill in the details of our star's biography. On June 5, scientists at the 222nd meeting of the American Astronomical Society in Indianapolis described a fledgling solar twin called TW Hydrae, which appears to be in its terrible twos.

TW Hydrae currently has 80 percent of the Sun's mass but is just 10 million years old. The researchers, headquartered at the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, have been watching the star grow as it collects gas from the protoplanetary disk that swirls around it.



SPITTING IMAGE. This artist's conception of TW Hydrae, a young star that will grow up to be similar to the Sun, shows the clumpy gas that streams toward the sun. By observing this stellar system, scientists can learn more about what our own star was like in its formative years. DAVID A. AGUILAR (CfA)

As the gas falls toward the star, a shock wave heats the gas and causes it to emit X-rays. The gas soon cools and emits lower-energy optical light as it heads even closer to the star.

"By gathering data in multiple wavelengths, we followed the gas all the way down," says lead scientist Nancy Brickhouse of the CfA. "We traced the whole accretion process for the first time."

And in watching that process, they discovered that gas doesn't pack onto the star continuously but in clumps. Some of the material never even makes it to the star because the stellar wind pushes it away, or it falls into the magnetic loops and prominences that our comparatively calm Sun also has.

The team will continue to investigate the interplay between TW Hydrae's magnetic activity and its growth. Understanding that connection will help fill in the gaps in our knowledge of how our solar system came to be the mature and developed place it is today. — **S. S.**

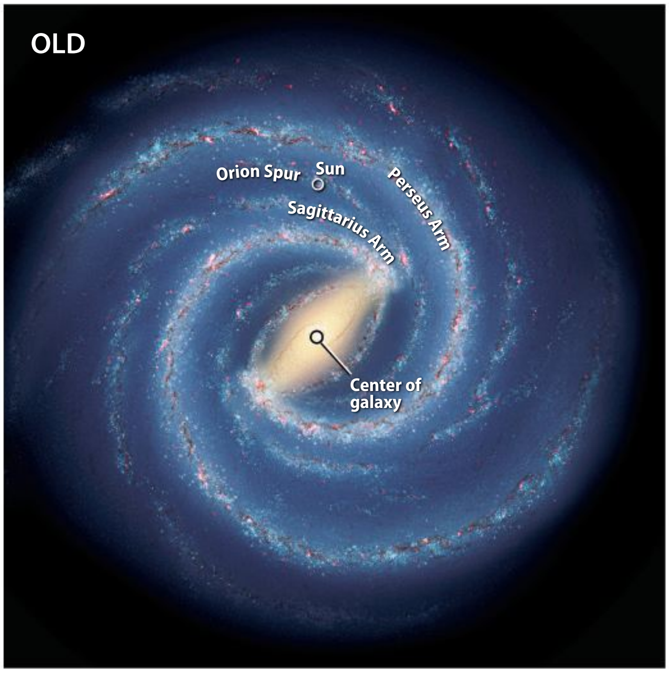
STRIPPED STAR. The smaller member of the J0247–25 binary system is evolving from a red giant to a white dwarf. KEELE UNIVERSITY

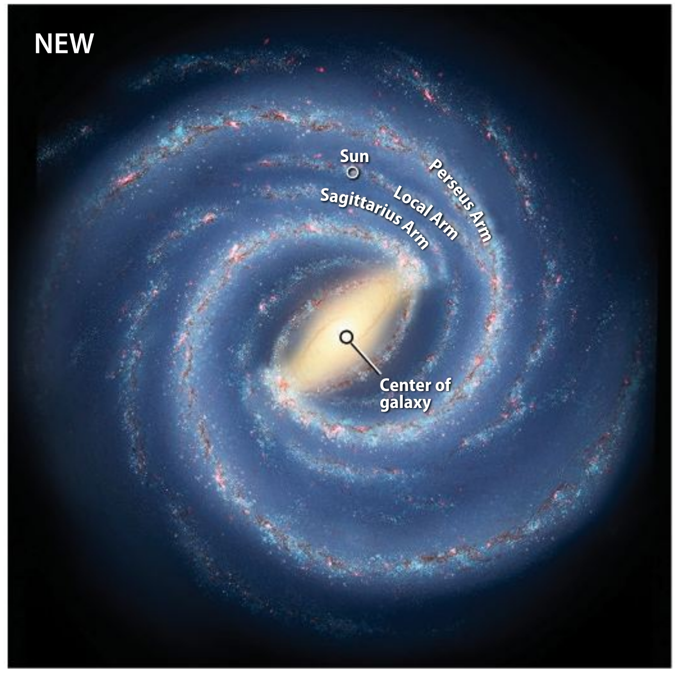
Stellar evolution intermediary

Astronomers describe in the June 27 issue of *Nature* the discovery of a star in the intermediate evolutionary stage between a red giant and a white dwarf. This sun, J0247–25B, also pulsates in a way not seen before, which can help scientists learn about the star's interior.

They hope to detect similar pulsations from other stars that might be in the same evolutionary phase and fill in the gaps of stellar evolution. — **L. K.**

TESTING LISA. As of June 4, the optical bench of the Laser Interferometer Space Antenna (LISA) Pathfinder has passed testing, including surviving the 35g force it will experience during its 2015 launch.





UPWARD MOBILITY. While the old conception of the Milky Way (left) showed the Local Arm as a mere spur of a larger limb, a new picture shows it to be a significant structure of its own. ROBERT HURT (IPAC) (OLD); BILL SAXTON (NRAO/AUI/NSF) (NEW)

The Milky Way's Local Arm is metropolitan

Earth's arm of the galaxy is muscular, astronomers announced June 3 at the 222nd American Astronomical Society meeting in Indianapolis. While the Local Arm first appeared to be a mere "spur" of the larger Sagittarius or Perseus arms between which it is sandwiched, new evidence shows it to be a significant limb on its own.

Scientists' conception of our galaxy is still evolving because determining the Milky Way's shape is like mapping a building while stuck in your office. Astronomers cannot step outside and observe the overall structure, so they have to get creative. To upgrade the Local Arm to a metropolitan area, the Bar and Spiral Structure Legacy (BeSSeL) survey team monitored the motions of molecules.

BeSSeL observes natural masers, which are like lasers that emit lower-energy electromagnetic radiation — in this case, water and methanol molecules that beam photons of a specific radio frequency into space. Astronomers then measure individual masers' velocities and parallaxes — how much they appear to move relative to a distant background as Earth travels around the Sun. The larger the change, the closer the maser. The Very Long Baseline Array, which made these observations, can resolve apparent position changes as small as 0.00017 arcsecond — the size a tennis ball appears from 4,800 miles (7,700 kilometers) away.

"Our Local Arm is … a major structure," says Alberto Sanna of the Max Planck Institute for Radio Astronomy in Bonn, Germany, "maybe a branch of the Perseus Arm, or possibly an independent arm segment." Either way, our picture of the Milky Way is changing and may continue to do so as telescopes become increasingly precise and sophisticated. — **S. S.**

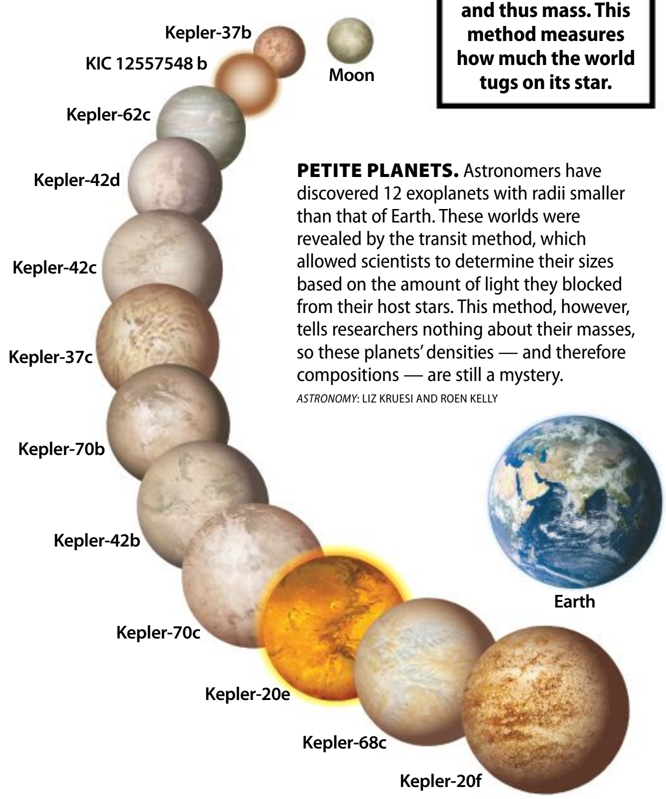
32 kelvins

The range of twice-a-day temperature swings in the martian atmosphere, as detected by NASA's Mars Reconnaissance Orbiter, according to a report in the May 28 issue of *Geophysical Research Letters*.

HOW MANY KNOWN EXOPLANETS SMALLER THAN EARTH EXIST?

FAST FACT

An extrasolar planet detected via the "radial velocity" method gives away its gravity and thus mass. This method measures how much the world tugs on its star.



PETITE PLANETS. Astronomers have discovered 12 exoplanets with radii smaller than that of Earth. These worlds were revealed by the transit method, which allowed scientists to determine their sizes based on the amount of light they blocked from their host stars. This method, however, tells researchers nothing about their masses, so these planets' densities — and therefore compositions — are still a mystery. *ASTRONOMY*: LIZ KRUESI AND ROEN KELLY

BY KARRI FERRON

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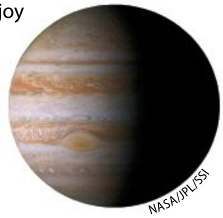
The Sky this Week

A daily digest of celestial events



NASA/ESA/LAURENT LAMY (PARIS OBSERVATORY)

NASA/JPL/SSI

Only have a little time each night to enjoy the wonders of the cosmos and want something quick and easy to observe? Look no further than Astronomy.com's "The Sky this Week." Written by Senior Editor Richard Talcott, this popular section highlights one or two sky events each night that you can observe through binoculars or a small telescope — many with just your naked eyes. In 10-day increments, learn when and where to spot each planet, the best meteor showers, bright comets and asteroids, the occasional double star, a few deep-sky objects, and more.

Each daily entry offers essential details of the event and how to locate it in your sky. Many of the week's most significant occurrences also feature an image or an *Astronomy* magazine star chart to help you witness what's going on overhead. See what's on tap for tonight at **www.Astronomy.com/skythisweek**.

JEFF BUELL

OBSERVING TOOLS

Fall observing videos

As temperatures drop and nights get longer, great objects appear in the sky for you to target, and *Astronomy*'s editors will help you find the best with the Astronomy.com seasonal observing videos. Senior Editor Michael E. Bakich gears one video toward beginning observers and easy targets. In another, he focuses on autumn objects you can see through a small telescope, such as the Andromeda Galaxy (M31) and the Double Cluster (NGC 869 and NGC 884). And in a third video, Editor David J. Eicher shares 10 of his favorite fall deep-sky objects, from the Bubble Nebula (NGC 7635) to Stephan's Quintet. Check out them all at **www.Astronomy.com/videos**.

COMMUNITY

Reader Photo Gallery

Browse thousands of beautiful astroimages like this one of the Bubble Nebula (NGC 7635) taken by Rod Pommier. Catalogs include Galaxies, Nebulae, Stars and Star Clusters, Planets, the Sun and Moon, Comets, and Cosmic Creations. Comment on photos and learn from other imagers' techniques. Beginners and advanced photographers anywhere in the world are welcome at **www.Astronomy.com/readergallery**. We publish new photos regularly!

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TOP 10 EXO

Astronomers have discovered nearly 1,000 planets orbiting other stars. Here we highlight 10 of the most dramatic systems in the exoplanet zoo.

by Richard Talcott

For decades, astronomers scanned the skies searching for planets around other stars. The searches proved fruitless until 1991, when Aleksander Wolszczan and Dale Frail found a system of planets circling an exotic pulsar cataloged as PSR B1257+12. Four years later, Michel Mayor and Didier Queloz discovered a Jupiter-sized world orbiting a normal star, 51 Pegasi, every 4.2 days.

Although these first two planetary systems were totally different from each other, they shared one significant characteristic: They were nothing like what astronomers expected — or even imagined. Basing their ideas on our solar system, scientists thought they would find small rocky planets close to their host star and big gaseous planets far away. Nature, however, had other ideas. The nearly 1,000 planets now known have given astronomers a rich mix of strange, and not so strange, worlds to explore.

Richard Talcott *is an* Astronomy *senior editor and author of* Teach Yourself Visually Astronomy *(Wiley Publishing, 2008).*

Although each exoplanet is unique, some rise higher above the crowd than others. The editors of *Astronomy* chose 10 as the most fascinating, exciting, intriguing — the coolest, if you will — known worlds. Some are individual planets, exceptional in their own right, while others are systems of worlds in remarkable environments. The only thing certain about the list is that it is destined to change in the years to come as astronomers continue their hunt.

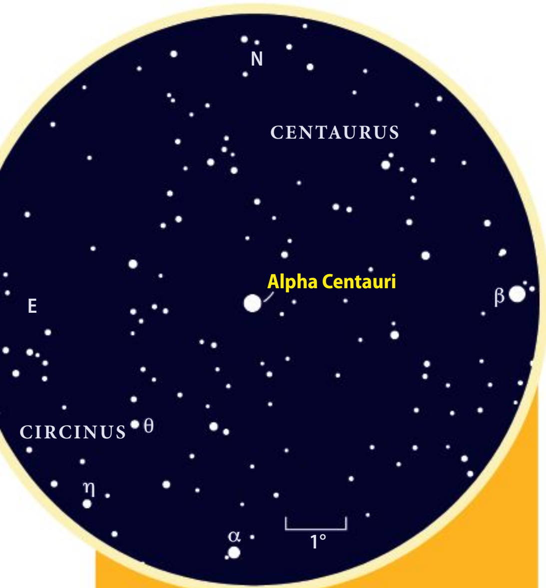
1 Alpha Centauri Bb

Finding a planet about the size of Earth orbiting a star similar to the Sun has been a holy grail of sorts for exoplanet hunters. They achieved this quest in 2012 when Xavier Dumusque of the Geneva Observatory in Switzerland and colleagues discovered a planet about 10 percent heavier than our world circling a star with 93 percent of the Sun's mass. Even better, the new planet resides next door, just 4.36 light-years from Earth in the closest star system to our own.

Unfortunately, Alpha Centauri Bb does not lie in its star's habitable zone — the region where temperatures

PLANETS

Alpha Centauri B looms on the horizon of its lone known planet, with Alpha Centauri A shining brightly above it and our Sun a speck to its upper right. ALL PLANET ILLUSTRATIONS BY RON MILLER; FINDER CHARTS BY *ASTRONOMY*: ROEN KELLY



ALPHA CENTAURI Bb

Coolness factor: Closest exoplanet to Earth
Mass (Earths): 1.1
Orbital radius (AU): 0.042
Discovery year: 2012

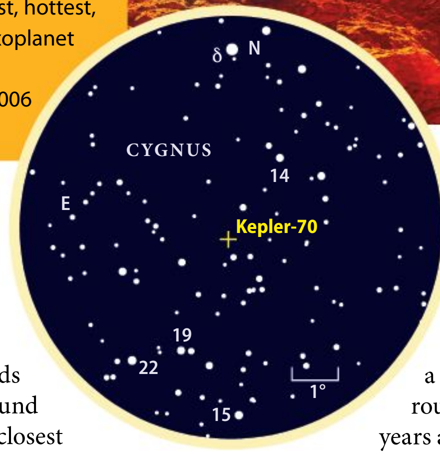
would allow water to exist as a liquid. The world orbits just 0.042 astronomical unit (or AU; 1 AU is the average distance between the Sun and Earth, or about 93 million miles [150 million kilometers]) from its host star, Alpha Centauri B. Its surface temperature likely reaches 2200° Fahrenheit (1200° Celsius).

Alpha Centauri B belongs to a tight binary star system with a slightly larger and brighter companion, Alpha Centauri A. The two orbit their common center of mass every 80 years at an average distance of 17.6 AU. The technique that Dumusque's team used to unearth the new planet pushed current technology to the limit, however, and the researchers say others need to repeat the observations to nail down this neighboring world's existence.

Scorched soil is the rule on Kepler-70b, which orbits its post-main sequence star at a distance of about 560,000 miles (900,000 kilometers).

KEPLER-70b

Coolness factor: Fastest, hottest, and least massive exoplanet
Mass (Earths): 0.44
Orbital radius (AU): 0.006
Discovery year: 2011



2 Kepler-70b

When it comes to superlatives, it's hard to beat Kepler-70b. Among the records it currently holds (at least among planets around normal stars) are: It orbits closest to its parent star, at a distance of 0.006 AU (Mercury lies 65 times farther from the Sun); it has the fastest average velocity, moving at a breakneck 608,000 mph (980,000 km/h); and it has the smallest mass, weighing just 44 percent of what Earth does. Only a couple of the oddball planets circling pulsars beat any of these numbers. And Kepler-70b stands alone as the hottest known exoplanet, with the noontime temperature reaching an estimated 12,500° F (6930° C).

These may not be even the planet's most impressive aspects. Kepler-70b and its sister world, the slightly larger, more distant, and cooler Kepler-70c, orbit a star that has already evolved off the main sequence. Kepler-70 spent several billion years on the main sequence, when it stably fused hydrogen into helium in its core. The star then swelled into a red giant until, roughly 18 million years ago, helium ignited in its core. The star then shrunk to its current size.

The two planets would have been inside the red giant's bloated atmosphere. Astronomers suspect that they were once gas-giant worlds akin to Jupiter. Then, as the star's outer layers expanded, its heat evaporated the planetary atmospheres. The dense cores left behind are the hot cinders we now see orbiting Kepler-70.

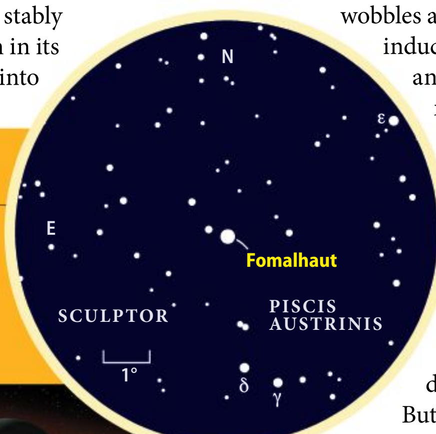
3 Fomalhaut b

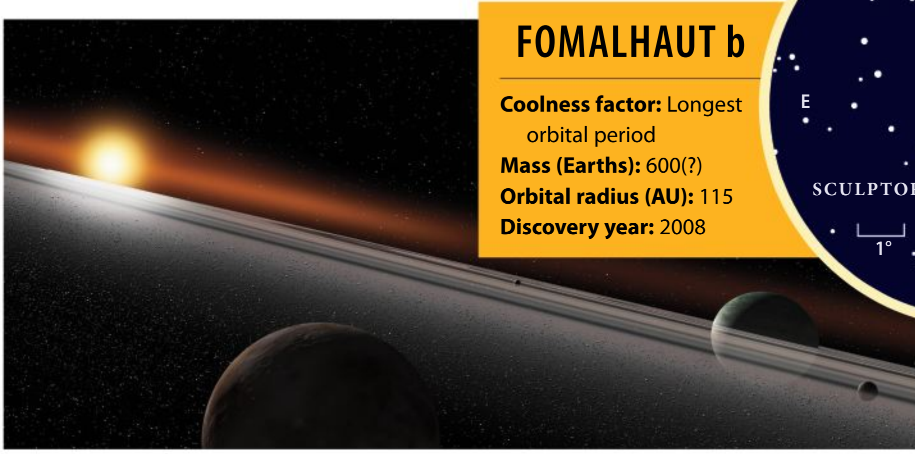
The majority of exoplanets discovered to date orbit close to their stars and don't take long to complete a circuit. The reason is simple. The two techniques that have turned up the most planets — the radial-velocity method that detects the wobbles a planet's gravity induces in a star's motion and the transit method that identifies the slight dips in a star's brightness caused when a planet passes in front of it — both find close-in worlds more easily than their distant cousins.

But astronomers have found a handful of planets by directly imaging them.

FOMALHAUT b

Coolness factor: Longest orbital period
Mass (Earths): 600(?)
Orbital radius (AU): 115
Discovery year: 2008

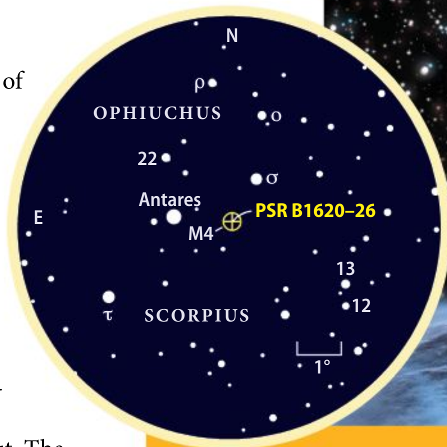




A huge dust ring encircles the star Fomalhaut (top left) along with at least one planet, which spends some of its 876-year orbit within the ring.

Although spotting the dim glow of one of these worlds near its host star's glare is a bit like seeing a firefly next to a searchlight, big telescopes can do it under the right conditions. And, unlike the other search techniques, imaging tends to find objects well away from their stars.

Researchers used the Hubble Space Telescope to detect Fomalhaut b in its wide-ranging orbit around 1st-magnitude Fomalhaut. The giant planet completes an orbit in about 876 years, more than five times longer than Neptune takes to circle the Sun. In this period, Fomalhaut b likely traverses at least part of the dusty disk that surrounds its parent star.



PSR B1620–26 b

Coolness factor: Oldest planet
Mass (Earths): 800(?)
Orbital radius (AU): 23
Discovery year: 2003

The rarefied atmosphere of PSR B1620–26 b glows with auroral emissions as its host star gleams against the surrounding suns of globular cluster M4.

4 PSR B1620–26 b

Although Earth formed approximately 4.65 billion years ago, it's a mere adolescent compared with PSR B1620–26 b. This planet was born some 13 billion years ago, when the Milky Way Galaxy itself was growing into the majestic spiral it is today. The gas-giant world resides just outside the core of the globular star cluster M4, whose stars and planets all developed within several hundred million years after the Big Bang that gave birth to the cosmos.

PSR B1620–26 b possesses roughly 2.5 times the mass of Jupiter and takes approximately 100 years to complete an orbit. The planet revolves around a tight binary system composed of a millisecond pulsar (which formed in the aftermath of a massive star's supernova explosion) and a white dwarf (the hot core left behind after a Sun-like star exhausts its nuclear fuel and ejects its outer layers).

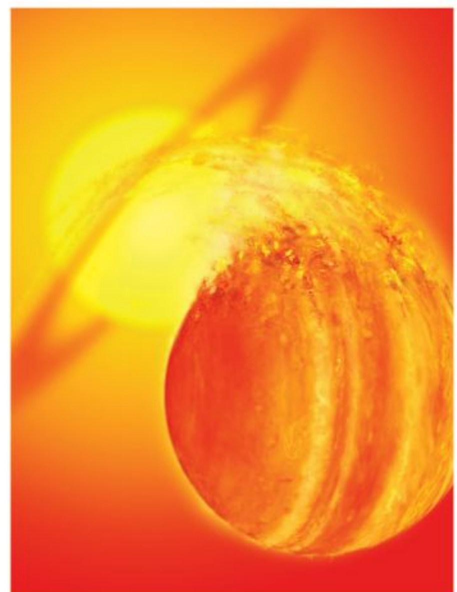
Astronomers think the system formed in multiple stages. The massive star initially belonged to a binary system. The bigger component quickly evolved and exploded, leaving behind a neutron star and a smaller companion. Meanwhile, the planet coalesced in a disk surrounding an unrelated Sun-like star. Then, a couple of billion years ago, the two systems collided. Gravitational interactions ejected the neutron star's original companion, and the planet ended up in a wide orbit around both its parent and the neutron star. When the Sun-like star swelled into a red giant some 500 million years ago, material flowed onto the neutron star and spun it up to become a millisecond pulsar. The entire system then settled down into the bizarre trio we see today.

5 WASP-12b

Perhaps no planet epitomizes the concept of a "hot Jupiter" better than WASP-12b. This type of world — with a mass in the same ballpark as our solar system's largest planet but an orbit that carries it close to its host star — first came to astronomers' attention in 1995. In that year, scientists discovered a Jupiter-sized planet circling the star 51 Pegasi once every 4.2 days. Not only was 51 Peg b the first planet discovered around a normal star, but it also opened researchers' eyes to the complexity lurking in the exoplanet zoo.

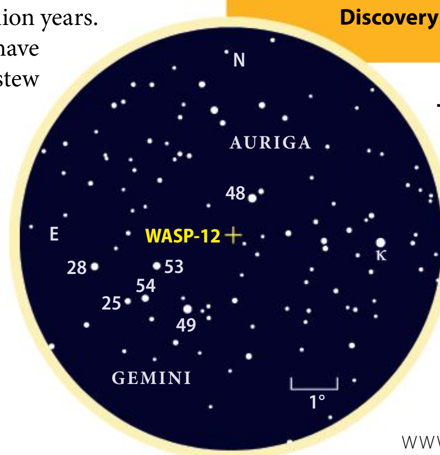
WASP-12b is even more extreme. This 1.4-Jupiter-mass planet orbits its parent star, which is slightly bigger and hotter than the Sun, once every 1.1 days. This proximity superheats the world to a temperature of around 4700° F (2650° C), causing the atmosphere to balloon out to nearly three times Jupiter's diameter. Hubble Space Telescope observations show that the planet can't survive these conditions much longer. Its atmosphere bleeds into space and spills onto its star. Researchers estimate it will lose its atmosphere in 10 million years.

WASP-12b also may have the richest atmospheric stew of any known exoplanet. Astronomers have identified several molecules in its steamy atmosphere, including water, methane, and carbon monoxide, and metals such as aluminum, magnesium, tin, and vanadium.

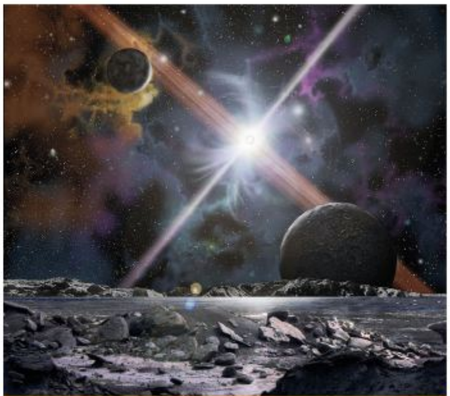


WASP-12b

Coolness factor: Exoplanet being devoured by its star
Mass (Earths): 450
Orbital radius (AU): 0.02
Discovery year: 2008



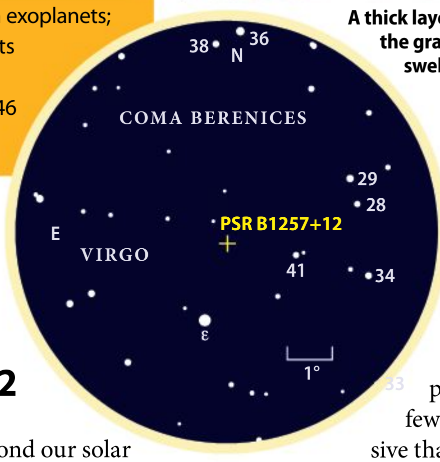
The bloated atmosphere of WASP-12b is siphoned off by the gravitational pull of its parent star, which lies in the background.



PSR B1257+12 SYSTEM

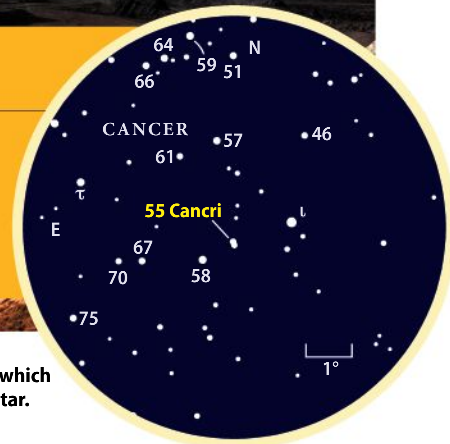
Coolness factor: First known exoplanets; second-generation planets
Mass (Earths): 0.02–4.1
Orbital radius (AU): 0.19–0.46
Discovery year: 1991

A trio of desolate planets orbits the millisecond pulsar PSR B1257+12. These three worlds were the first discovered beyond our solar system.



55 CANCRI e

Coolness factor: Planet made of diamond?
Mass (Earths): 8.4
Orbital radius (AU): 0.016
Discovery year: 2004



A thick layer of diamond likely lies beneath the graphite-rich surface of 55 Cancri e, which swelters in the shadow of its nearby star.

6 PSR B1257+12 system

As the search for worlds beyond our solar system heated up in the early 1990s, planet hunters targeted stars similar to the Sun. So, you can imagine the shock most scientists felt when the first planets turned up around a star totally unlike the Sun during a research project in which planets didn't even rise to the level of afterthought.

Aleksander Wolszczan and Dale Frail were seeking millisecond pulsars when they found PSR B1257+12. This neutron star — an object formed when a massive star explodes and leaves behind a remnant as dense as an atomic nucleus — spins once every 6.22 milliseconds. Radio pulses from such objects repeat with precise regularity, so when Wolszczan and Frail noticed a pattern of changes to the pulses, they knew something was up. The timing shift indicated gravitational wobbles induced by three orbiting planets — two a few times more massive than Earth and one close to the Moon's size.

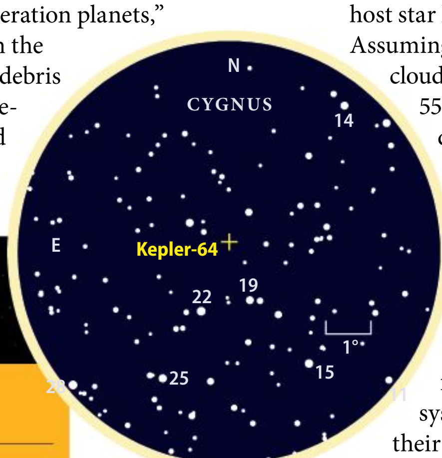
But the pulsar planets make our list of cool exoplanets for more than one reason. Most planets are born in dusty disks surrounding their parent stars while those suns condense from the interstellar medium, but the supernova that created PSR B1257+12 would have destroyed any pre-existing worlds or hurled them far into space. The pulsar planets must be "second-generation planets," formed from the supernova's debris or from material captured from a companion star.

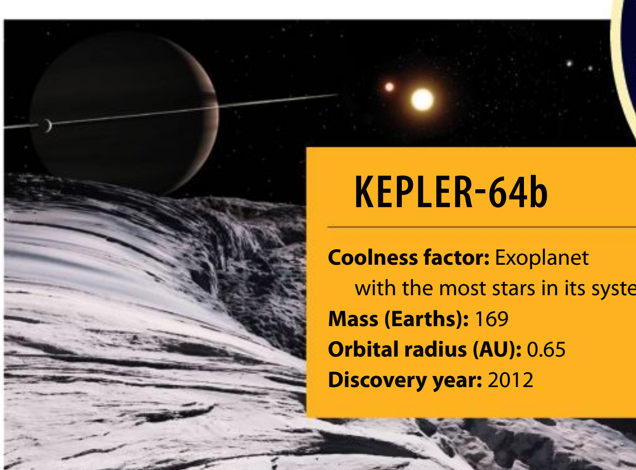
7 55 Cancri e

If diamonds are a girl's best friend, the next husband or boyfriend who finds himself in love or in trouble may want to book passage for 55 Cancri e. If scientists' models are right, this exoplanet may have a thick layer of diamond lurking beneath a hardened surface of graphite.

Although the scientific idea that diamond planets could exist has been around for a decade or more, 55 Cancri e became the first likely candidate in 2012. Astronomers discovered the planet in 2004, but it took years before observations became detailed enough to characterize 55 Cancri e. NASA's infrared-sensitive Spitzer Space Telescope pinned down the world's mass and radius, allowing researchers to determine its density, which isn't much different from Earth's. Other studies showed that its host star has a large abundance of carbon. Assuming the planet formed out of the same cloud as the star, scientists conclude that 55 Cancri e has a subsurface layer of diamonds many miles thick.

The planet is a world of extremes. It lies just 0.016 AU from its star and completes an orbit in less than 18 hours. And the world's day side bakes at temperatures that soar above 3200° F (1750° C). Any of the four other planets in the 55 Cancri system, which all lie farther from their sun, would make a better base than e for any diamond-mining operations.





KEPLER-64b

Coolness factor: Exoplanet with the most stars in its system
Mass (Earths): 169
Orbital radius (AU): 0.65
Discovery year: 2012

A crescent Kepler-64b (far left) appears near its binary star host with the quadruple system's more distant suns at top right.

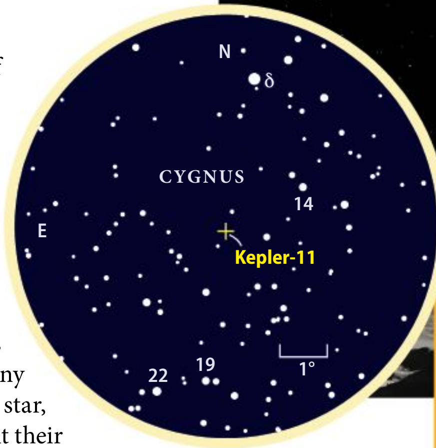
8 Kepler-64b

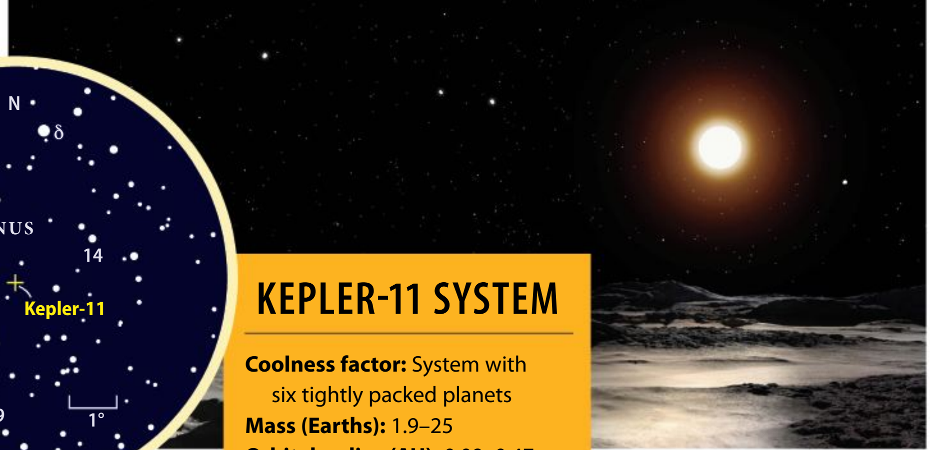
Viewed in isolation, Kepler-64b doesn't seem all that remarkable. This

world possesses a mass of some 169 Earths (a bit more than half of Jupiter) and completes an orbit every 138 days at a distance of 0.65 AU, which would place it slightly inside Venus' orbit in our solar system.

But Kepler-64b stands out because of the company it keeps. It circles not one star, but a pair. These two orbit their common center of mass once every 20 days, and each one eclipses the other during every circuit. This makes Kepler-64b one of a handful of known circumbinary planets. The larger of the stars weighs about 1.5 Suns while the smaller one checks in at 0.4 solar mass. But don't confuse this type of binary host with Alpha Centauri B; in that nearby system, the planet orbits one of the two stars.

What truly sets this system apart, however, is that it travels through space with a second set of stars in tow. This other stellar pair lies approximately 1,000 AU (roughly 30 times the distance between the Sun and Neptune) from the planet-bearing stars. The dynamics of the quadruple star system gives Kepler-64b a noteworthy survival story, and a so-far unique one in the burgeoning field of exoplanet searches.





KEPLER-11 SYSTEM

Coolness factor: System with six tightly packed planets
Mass (Earths): 1.9–25
Orbital radius (AU): 0.09–0.47
Discovery year: 2011

From the barren surface of Kepler-11g, its host star and five planetary siblings would all line up.

9 Kepler-11 system

When it comes to stars with lots of planets, our solar system still reigns supreme. But Earth and its seven major siblings likely won't be king much longer. At least four other stars — Gliese 667C, HD 10180, HD 40307, and Kepler-11 — have families with six confirmed planets, and some of these show hints of other possible members.

Of these systems, the one belonging to Kepler-11 stands out for its compact configuration. It's as if nature were trying to make an entire family live in a one-room apartment. All six planets orbit closer to the star than Venus does to the Sun, and the inner five would fit comfortably inside Mercury's orbit. These aren't small worlds, either — their masses range from about twice Earth's up to slightly bigger than Neptune's. Although this planetary system bears little resemblance to ours, its star closely mimics the Sun. Kepler-11 possesses 95 percent of our star's mass, and its radius is about 10 percent larger.

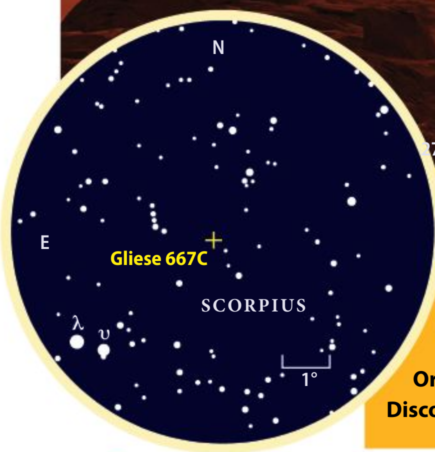
10 Gliese 667C system

The search for life in the universe may have just gotten a bit easier. In June 2013, astronomers announced that the star Gliese 667C possesses three planets within its habitable zone, where water could exist as a liquid on the surface. All three are so-called super-Earths that have masses larger than our home world but smaller than 15 Earth masses, the size of Uranus. These worlds completely fill the star's habitable zone — no other hypothetical planet could occupy a stable orbit within the zone.

The three belong to a system that holds at least six (and possibly seven) planets. All orbit the star Gliese 667C, the faintest member of a triple star system located approximately 22 light-years from Earth. Gliese 667C has about one-third the Sun's mass and a surface temperature barely half that of our star's. These conditions mean the three habitable worlds lie quite close to their parent, between 0.13 and 0.21 AU away, so they would fit inside Mercury's orbit in our solar system.

Although the three planets in Gliese 667C's habitable zone may not be inhabited, their mere existence raises the hopes of scientists seeking life beyond our solar system. Because red dwarf stars like Gliese 667C make up the majority of stars in our galaxy, the discovery increases the chances of finding other worlds where life could gain a foothold.

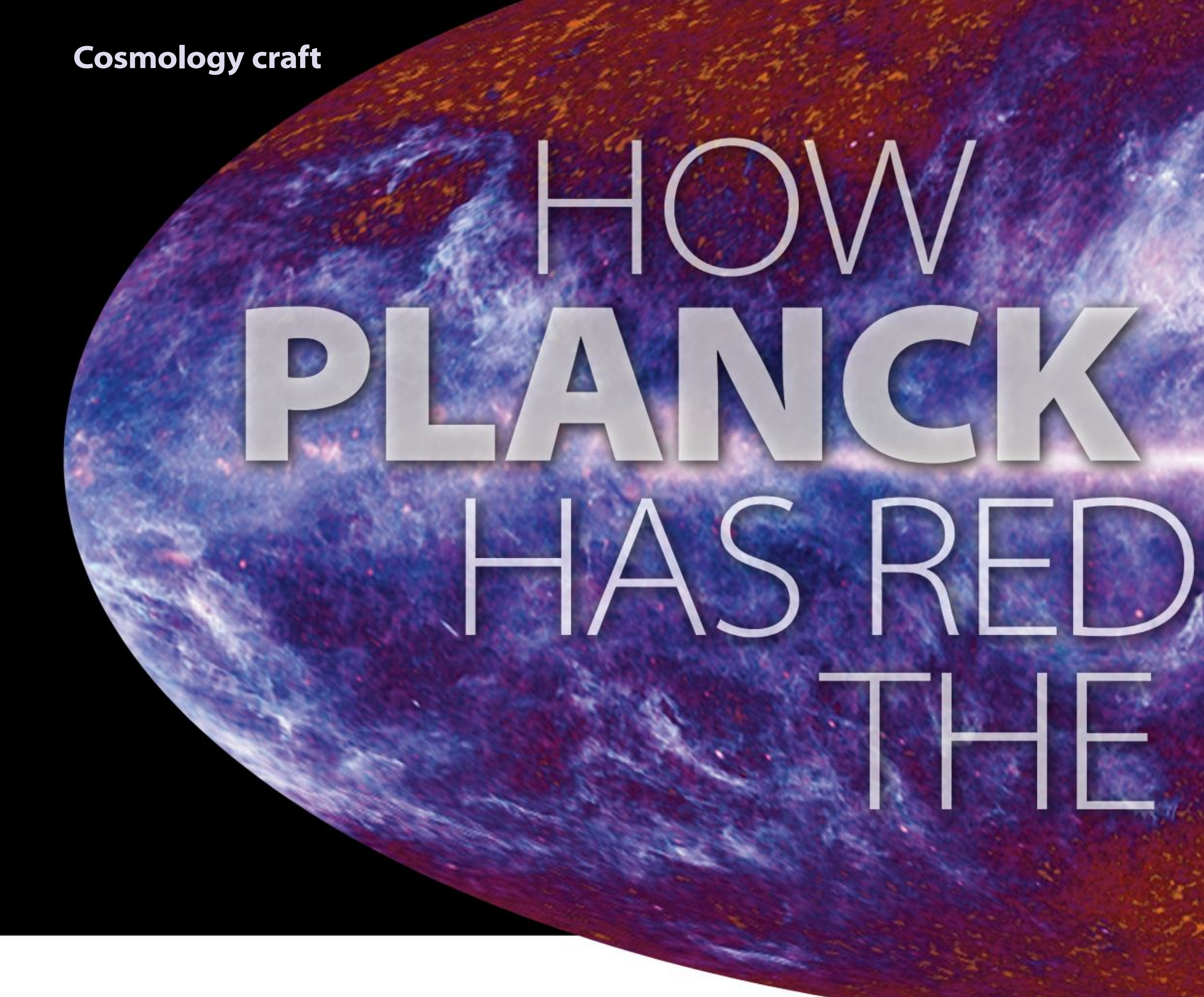
Three super-Earth planets exist in the habitable zone — where liquid water can survive on the surface — of the red dwarf star Gliese 667C.



GLIESE 667C SYSTEM

Coolness factor: Three planets in habitable zone
Mass (Earths): 2.7–6.9
Orbital radius (AU): 0.05–0.55
Discovery year: 2009–2013

THE EXOPLANET ZOO CONTAINS PLENTY OF EXOTIC WORLDS. READ ABOUT FIVE THAT JUST MISSED OUR LIST AT **www.Astronomy.com/toc.**



HOW PLANCK HAS RED THE

The Planck spacecraft — the culmination of nearly two decades of nonstop effort by hundreds of scientists and engineers — has given astronomers their best look ever at the infant cosmos. Since 2009, the probe has been mapping the microwave universe and gathering data on our Milky Way, galaxies across cosmic time, and the cosmic microwave background (CMB) — the Big Bang's relic radiation. It's certainly not the first craft to study the CMB, but Planck has produced the most detailed observations of this pervading radiation across the cosmos.

Now, Planck's first cosmology results, announced in 29 scientific papers in March, have confirmed astronomers' leading theory of the universe. They have refined many cosmic parameters, such as the universe's age, how fast it is expanding, and what it's composed of. But just as important as these much-publicized findings are the other results that lie within the Planck data and just how scientists managed to extract that information. For embedded within the sea of microwave signals is a map of the universe's matter across cosmic time, secrets of enormous gravitationally bound superclusters of galaxies, and thousands of newly cataloged objects.

Astronomers have made a discovery workhorse of the European Space Agency's (ESA) Planck mission and revealed a microwave universe never before seen.

Liz Kruesi, *an* Astronomy *associate editor, writes frequently about cosmology and the universe's most extreme objects.*

Up and away

The Planck mission launched May 14, 2009, from Guiana Space Centre in Kourou, French Guiana. It collects light from a "Lissajous" orbit around the second Sun-Earth Lagrangian point, called L2. (This is one of five locations where the Sun's and Earth's gravitational forces equal each other, which allows Planck to maintain a stable orbit with little propellant.) The L2 point sits some 930,000 miles (1.5 million kilometers) from Earth in the direction opposite the Sun. Planck's solar panel blocks the heat and light from the Sun, Earth, and the Moon from blinding the spacecraft.

After weeks of cooling and calibrating the craft, astronomers began routine observations August 12, 2009. Planck completes one all-sky scan in six months, collecting data through its High Frequency Instrument (HFI) and its Low Frequency Instrument (LFI).

EFINED UNIVERSE

This new spacecraft has mapped the universe's matter, refined its composition and age, and revealed thousands of radio sources. **by Liz Kruesi**

Dust in our galaxy, cold prestellar objects, and the cosmic microwave background glow in long-wavelength microwave radiation. The Planck spacecraft has mapped this emission with better resolution than any previous all-sky microwave probe. ESA/LFI & HFI CONSORTIA

The helium-3 used in conjunction with helium-4 to cool Planck's HFI to 0.1 kelvin (–459.49° Fahrenheit) ran out January 13, 2012; the LFI, however, will collect data through September 2013. (See "Planck's instruments, and how they compare to others" on p. 30.) The March 2013 release incorporates 15.5 months of observations, so 2.5 surveys of the sky.

Getting to the signal

Planck collects information about the CMB radiation, but it also observes most energies with a frequency between 27 and 1,000 gigahertz. To see only the faint CMB signal, scientists have to remove seven types of signals they're not interested in from each of the instrument's nine channels.

One of their tricks is actually using Planck's nine frequency bands to better define what they're seeing. "We use the low-frequency instruments to map the galactic rubbish and subtract it out of the higher-frequency maps where we're looking for the CMB," says Bruce Partridge of Haverford College in Pennsylvania. "Dust in our galaxy and in external galaxies is very strong at the highest frequencies. We map it at the highest frequency and subtract it out of the intermediate frequencies."

The researchers know what the CMB's energy spectrum looks like — NASA's COsmic Background Explorer measured it in the 1990s. They then compare images through different filters of the same location on the sky. Specifically, they look for radiation intensity changes that correspond to astronomical objects. "Most of the foregrounds we're dealing with have a different spectrum from the microwave background," says Partridge. "So by having this wide frequency range, we can characterize the foregrounds much better."

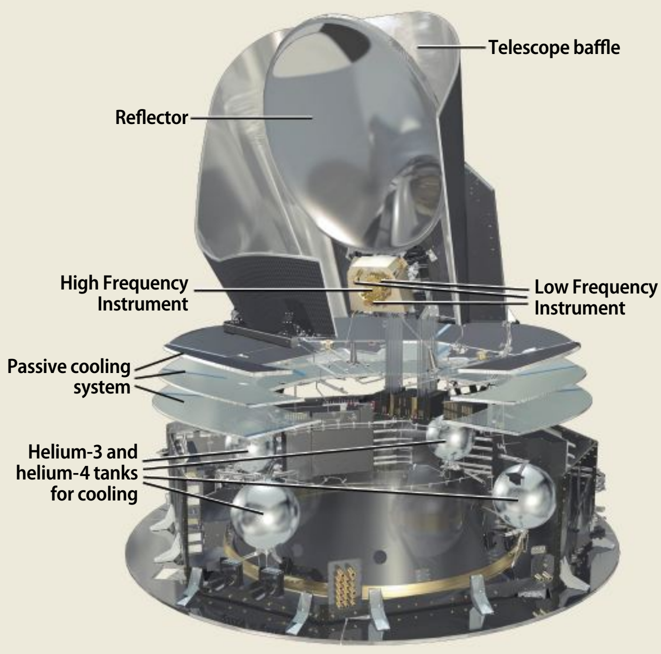
For example, high-energy particles in space — called cosmic rays — spiral along the Milky Way's magnetic field. As they change directions, they emit radiation that has a strong signal in Planck's lowest frequency bands.

Because scientists have been able to isolate these signals,

0.1 kelvin

The temperature Planck's High Frequency Instrument must be cooled to

PLANCK'S INSTRUMENTS, AND HOW THEY COMPARE TO OTHERS



A look inside the Planck spacecraft shows how much of the volume is dominated by cooling systems to ensure that the High and Low Frequency Instruments can detect temperature — and thus energy — differences a million times smaller than a degree. ESA/AOES MEDIALAB

Planck is the third-generation cosmic microwave background (CMB) spacecraft. The first one, the COsmic Background Explorer (COBE), measured the radiation's temperature profile in the 1990s accurately to 2.725 ± 0.002 kelvin (–454.8° Fahrenheit), matching the value that scientists' best theory hypothesizes. The Wilkinson Microwave Anisotropy Probe (WMAP), the second-generation CMB detector, then measured the CMB's temperature variations as it operated from 2001 through 2010.

WMAP and Planck work differently from COBE. Each measured how specific spots in the sky differ in temperature. But Planck views the sky across a wider range of the electromagnetic spectrum and can see finer details. WMAP's detectors had a sensitivity of 20 millionths of a kelvin and could resolve angles as small as 15 arcminutes (¼ degree); Planck's detectors have a sensitivity of two millionths of a kelvin and can resolve angles as small as 5 arcminutes (1⁄12 degree). It also can see wavelengths 10 times shorter than WMAP could.

Planck's High Frequency Instrument (HFI) collects light in six frequency bands — centered on 100 gigahertz, 143 GHz, 217 GHz, 353 GHz, 545 GHz, and 857 GHz. Each collection band has a width, and thus HFI covers most frequencies between 84 and 1,000 GHz. This range spans radiation with wavelengths from 3.6 millimeters to 0.3mm. (Visible light corresponds to energy with wavelengths between 390nm and 700nm, or roughly 1,000 times shorter.)

The Low Frequency Instrument (LFI) measures light across three bands between 27 and 77 GHz, which spans 11.1mm to 3.9mm.

HFI's detectors must be kept extraordinarily cold to register a radiation change. A four-step cooling system aboard Planck brings the instrument's temperature to just 0.1 K, making it the coldest place in space. LFI's detectors can operate at a higher temperature — about 20 K. — *L. K.*

they've also compiled catalogs of those foreground sources. One such release contains 24,119 compact sources (any spot on the sky that emits microwave radiation). Planck has given astronomers a radio playground to investigate.

Universe origins

Planck's main purpose, of course, is to precisely map the CMB. The past century of observational evidence — and especially other CMB measurements — has strengthened the Big Bang theory, which says the universe began some 13.8 billion years ago as a searing, densely compressed area of radiation and subatomic particles. Immediately afterward, our tiny universe expanded tremendously (10^{30}) in just 10^{-36} second; scientists call that fraction of time the "inflationary era." (Still an unobserved cosmic epoch, inflation is backed by mounds of evidence.)

After this period, the universe continued to expand (at a lower rate) and thus cool. A few minutes after the Big Bang, quarks combined to form protons and neutrons. Those particles sloshed around with electrons and radiation "bits," called photons. For thousands of years, radiation collided with other particles.

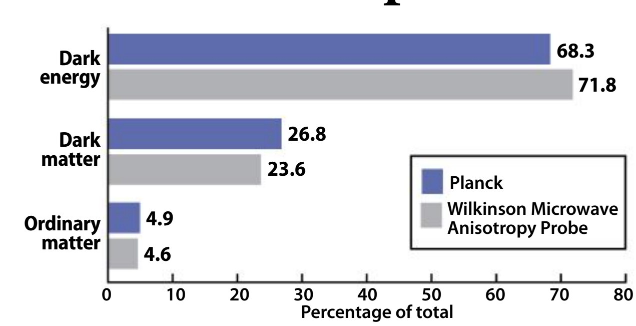
Then, when the universe had expanded enough to cool to 3000 K (4940° F), electrons and protons could combine as neutral hydrogen atoms, so photons had fewer particles to bounce off. The radiation could stream free. This "time of last scattering," as scientists call it, occurred about 370,000 years after the Big Bang. The light has been traveling since then, filling the universe and landing on astronomers' detectors as blips of energy. Cosmic expansion has stretched, or redshifted, that radiation's wavelengths from infrared to microwave.

This radiation carried with it a picture of what the cosmos looked like at the time of last scattering. Regions packed with slightly more mass were warmer. On the resultant Planck CMB temperature map, the redder (warmer) regions eventually pulled in more matter and formed into today's superclusters of galaxies. But that's not the only bit of information this map reveals.

Cosmic characteristics

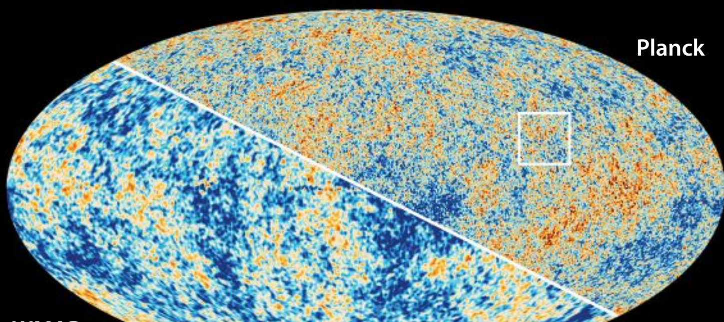
Planck scientists use the data compiled from the satellite's nine wavelength bands to determine an array of cosmic parameters — such as the universe's age and the amounts of normal, or baryonic, matter that stars and people are made of; dark matter, a mysterious invisible mass; and dark energy, what seems to be speeding up cosmic expansion. The CMB map may look clumpy with different-sized spots across the sky, but astronomers break apart this signal

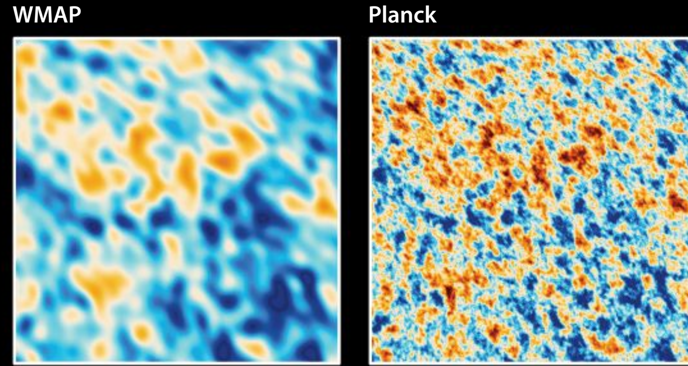
The cosmic recipe



Using the new data from Planck, astronomers have revised the percentages of ordinary matter, dark matter, and dark energy that make up the universe. *ASTRONOMY*: ROEN KELLY

A crisper view

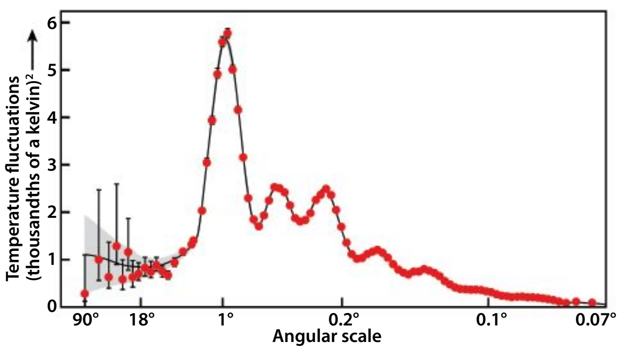




ESA AND THE PLANCK COLLABORATION; NASA / WMAP SCIENCE TEAM

Planck's map of the cosmic microwave background (CMB) shows details some three times smaller than the map from the previous-generation CMB satellite, the Wilkinson Microwave Anisotropy Probe (WMAP). The square outline on the map at left shows the region compared in the larger boxes, above.

Listen to the universe



ASTRONOMY: ROEN KELLY, AFTER ESA AND THE PLANCK COLLABORATION

The "angular power spectrum" shows the amount of fluctuation in the cosmic microwave background temperature at different angular scales on the sky. It is the single most important result from the Planck mission because it provides scientists with a way to find out how much stuff the universe holds, how much of that is ordinary versus dark matter, and additional characteristics of the early cosmos.

into its constituents. They essentially "bin" all the sizes — a certain number are 2° wide, 1° wide, ½° wide, and so on. They then plot how the temperature varies as a function of the sizes on the sky. This comparison is called the "angular power spectrum," and each bump on the plot corresponds to a "binned" variation size in the CMB map (see "Listen to the universe," above).

Planck scientists model a universe with six specific variations — for example, the density of baryonic matter and the fraction of photons that run into electrons — and compare that to the angular power spectrum compiled from the data to find the perfect match. From those six parameters, astronomers also can calculate many characteristics of the universe, like how fast it is expanding, its age, and its composition. "The cosmic background is the most important source of information about the universe at large and its contents, by far," says Charles Lawrence, the U.S. Planck project scientist located at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. "It has contributed more to our understanding of the universe than anything else."

Scientists can precisely model the early cosmos because they understand the physics of the universe at the time of last scattering. It was a hot mixture of particles and radiation but contained no galaxies or stars. It held just hydrogen, helium, deuterium, tritium, and a sprinkling of lithium, but no other elements. "The density was low, by the standards of the density on Earth — a few million particles per cubic meter," says Lawrence. "The behavior of the matter is known. You had electromagnetic interactions and gravity interactions. And the dark matter had a weak nuclear interaction. But you know how all this works; the physics of that time is understood really well."

Scientists with the prior-generation CMB craft — the Wilkinson Microwave Anisotropy Probe (WMAP) — incorporated nine years of data to find that the universe is 13.77 billion years old and holds 4.6 percent normal matter, 23.6 percent dark matter, and 71.8 percent dark energy. Using the new Planck map and power spectrum, scientists refined those characteristics: the universe is 13.82 billion years old, 4.9 percent of the cosmos is baryonic, 26.8 percent is dark matter, and 68.3 percent is dark energy. (The Planck team determined nearly 20 other parameters, too.)

Scanning for bigger structures

Analyzing the relic radiation gives scientists additional information about the universe — specifically, intervening material that alters CMB photons as they make their way to scientists' detectors. Most of the universe's baryonic matter is not in stars, but actually in hot gas, and galaxy clusters hold a lot of 10-to-100-million-degree gas. "Some small fraction of the CMB photons coming through this hot gas scatters off energetic electrons [in gas], while they modify the energy of the photons," says Lawrence.

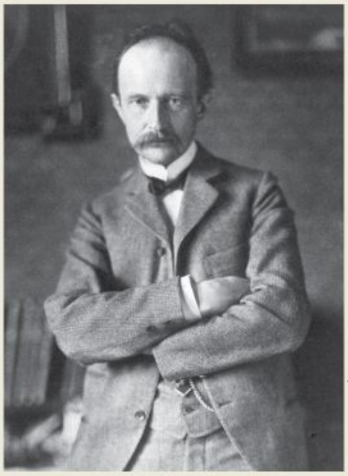
This changes the signal Planck receives in an understood way; the modification is called the Sunyaev-Zeldovich effect (SZe) after the physicists who theorized it. "Any cluster of galaxies will show up as either a slightly hotter or colder spot on the CMB map than it should be," explains Joanna Dunkley, a Planck team member at the University of Oxford in England.

Using the satellite's data, scientists compiled a catalog of 1,227 galaxy clusters. Out of those, they already knew of about half, but Planck confirmed 178 additional clusters and identified 366 candidate clusters. While analyzing these structures, however, they came across a possible problem that suggests astronomers don't fully understand the physics of galaxy clusters.

"The number of clusters we see doesn't quite match up to what we expected," says Dunkley.

"If you assume that the X-ray astronomers are right," adds

WHO WAS MAX KARL ERNST LUDWIG PLANCK?


AIP EMILIO SEGRÈ VISUAL ARCHIVES/W. F. MEGGERS GALLERY OF NOBEL LAUREATES

Max Planck was awarded the Nobel Prize in physics in 1918 for his work in quantum theory.

Born April 23, 1858, in Kiel, Germany, Max Planck's interest as a youth lay in music — specifically piano and organ. He considered a musical career prior to attending the University of Munich. There, his focus switched to physics.

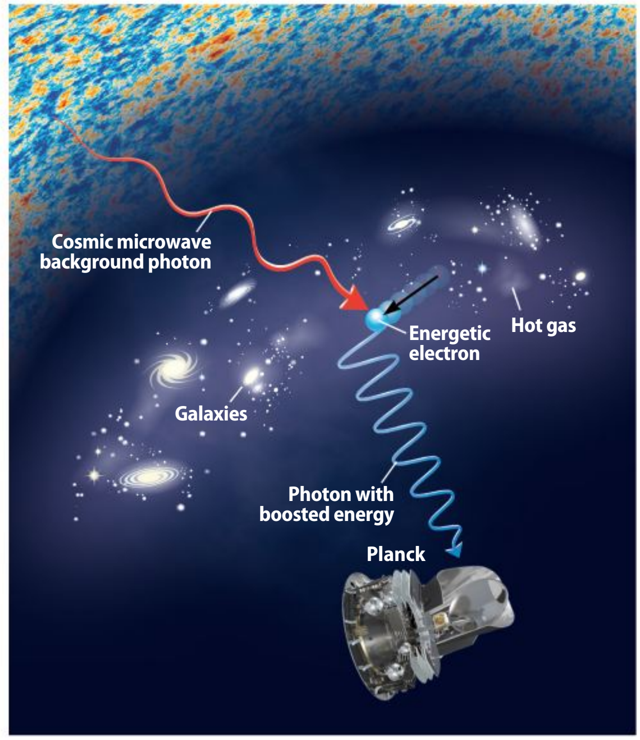
Planck spent a year studying at the University of Berlin — cementing his interest in radiative processes and thermodynamics. He earned a doctorate at the University of Munich in 1879 and taught there for a number of years.

In 1888, Planck joined the faculty at the University of Berlin, where he remained until his retirement in 1927. It was during this time that he studied how the intensity of the electromagnetic radiation emitted by a perfect absorber, also known as a cavity radiator or a black body, depends on light's color and the temperature of the absorber.

In 1900, he presented his research — that the energy comes in only discrete values, or quanta, that depend on a frequency. So for the frequency ν, the energy is $\hbar\nu$, where $\hbar$ is a constant (now called Planck's constant, with the value $6.62606957 \times 10^{-34}$ joule·second). He opened the doors to quantum theory without realizing it. Other luminaries (like Albert Einstein) would later build on Planck's research.

The Royal Swedish Academy of Sciences awarded Planck the 1918 Nobel Prize in physics "in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta." Much of his life after his discovery of quanta focused on thermodynamics research in addition to his being active in the German Physical Society and the Prussian Academy of Sciences. He died October 4, 1947, in Göttingen, Germany. — *L. K.*

Revealing galaxy clusters



As a light photon travels through the hot gas in a cluster of galaxies, it may collide with an energetic electron and steal some of its energy. Thus, the photon is slightly bluer when it arrives at a detector. Scientists look for this "Sunyaev-Zeldovich effect" in the cosmic microwave radiation to learn about intervening galaxy clusters. *ASTRONOMY*: ROEN KELLY

Partridge, "you ought to see a bigger signal in the microwave background with SZe."

Another finding that astronomers extract from the CMB data aligns better with the theoretical models. "We're using the cosmic microwave background as a backlight," says Dunkley. "So the CMB is traveling to us over billions of years, and it travels through space for billions of years. The gravity of basically everything it goes past bends that light ever so slightly." By analyzing the outcome of this "gravitational lensing" on the CMB data, the Planck team created a map of the distribution of all the matter in the universe between the surface of last scattering and the present time.

"It doesn't give us a high-resolution picture — Planck doesn't have that kind of ability," explains Lawrence, "but on large scales, we get all the mass. And that's really cool." Jan Tauber, the ESA Planck project scientist, adds, "Some people think it's more interesting than the CMB itself." This matter map agrees with the percentage of baryonic matter, dark matter, and dark energy. In fact, a universe with no dark energy would generate bigger lumps over time and have a much larger lensing signal. "We use this new data from Planck to add extra evidence for the existence of dark energy and how much of it there is," says Dunkley.

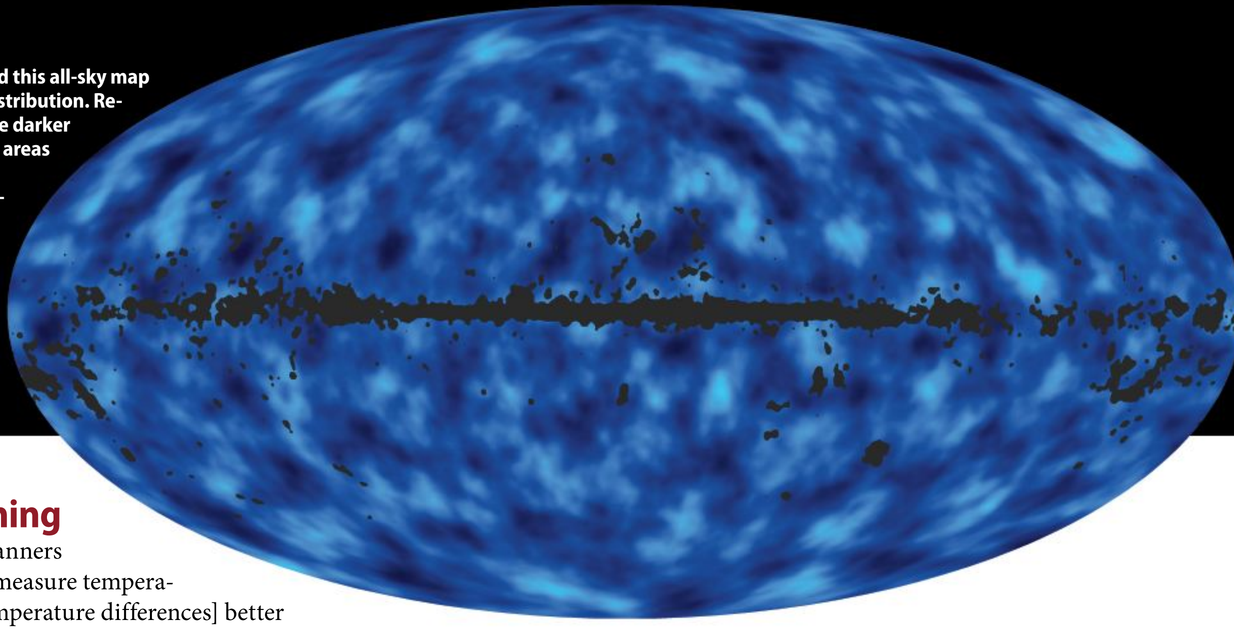
"With Planck, I would say the CMB lensing signal has transitioned from a theoretical construct to now being a useful cosmological tool," says Jamie Bock of JPL. "This is only the beginning, and I'm sure we are going to see many uses of CMB lensing to study galaxy formation and large-scale structure soon."

A few oddities

The CMB radiation map shows a few oddities as well. Scientists typically describe the universe as isotropic, meaning it looks the same from any viewpoint and thus has no preferential locations or directions. But a few subtle anomalies in the CMB raise questions: The signal at the largest angular scales seems to be weaker than expected, the two hemispheres appear to have slightly different average temperatures, and the all-sky map contains a large cold spot.

WMAP had hinted at the latter two anomalies, but "Planck showed skeptics like me that they were real, and not small problems in the data," says Partridge. These issues aren't large enough to throw out the leading model of the universe's evolution, but it does mean that perhaps astronomers don't fully understand the physics of the early cosmos and will need to revise the models in such a way that these signals are outcomes of the theory and not peculiarities.

24,119
The number of radio sources in Planck's compact source catalog



The Planck team released this all-sky map of the universe's mass distribution. Regions with more mass are darker blue in this image, while areas with less are lighter. The black horizontal band indicates where the Milky Way's disk lies across the sky, which is too bright for scientists to tease out cosmic mass information. ESA/NASA/JPL-CALTECH

To the beginning

Although mission planners designed Planck "to measure temperature anisotropies [temperature differences] better than ever, and in a sense, to be the final word" for those measurements, says Lawrence, the probe also collects data about the microwave radiation's polarization — from the Milky Way and also the CMB. People are familiar with polarization in a different form: Sunlight bouncing off a lake can have a preferred direction, and thus polarized sunglasses cut the glare by blocking light with a specific orientation. (This is because light acts like wave.)

Astronomers think the CMB radiation has two different types of polarization: E-mode, which results from CMB photons changing directions as they collide and then scatter off electrons; and B-mode, which is produced by gravitational waves originating from the universe's first moments. They've found E-mode polarization, but B-mode corresponds to a much fainter signal.

According to the Big Bang theory, during the inflationary period that lasted for just a fraction of a second, quantum fluctuations expanded. (These density variations eventually led to structures like today's galaxies and galaxy clusters.) As the universe expanded, so did those fluctuations, causing ripples in space-time — gravitational waves. "Gravitational waves basically leave an imprint on matter after inflation," explains Tauber.

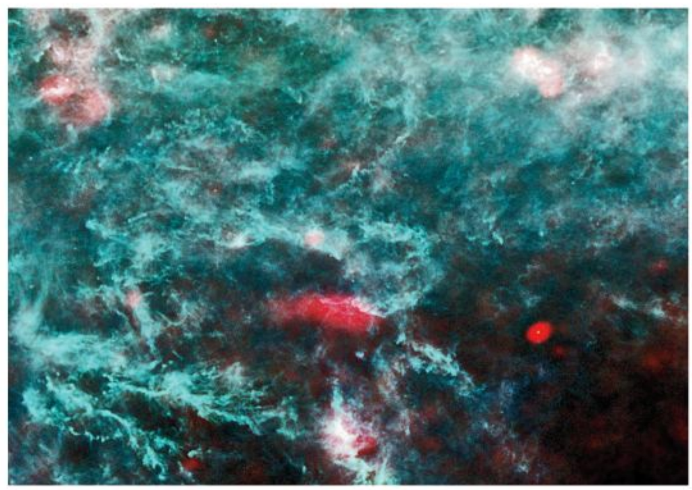
Cosmologists are on the hunt for evidence of those ripples, which would show up as "a very specific pattern of polarization around hot and cold spots in the temperature of the CMB — the so-called B-mode signal," says Partridge.

"It's very hard to produce B-mode polarization any other way" than through inflation, he adds.

"So that's what we're going to be looking for, with the caveat that they're expected to be very weak," says Tauber. "It's quite uncertain whether we will be able to find that particular signature." And finding this signal would help astronomers narrow down what happened during inflation — if this hyper-acceleration actually occurred. (They have hundreds of inflationary theories to swim through.)

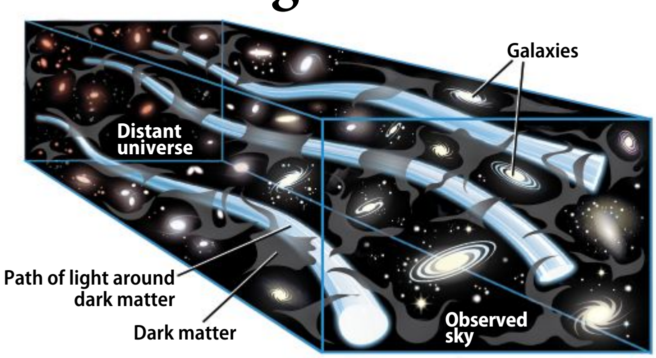
Planck scientists hope to tease out this signal in their next data release, which is currently set for mid-2014. This next analysis will include 29 months (more than four all-sky surveys) of HFI data and 50 months (some eight all-sky surveys) of LFI measurements — this is all of the data that the instruments have collected.

"Finding this B-mode signal is the next big thing in the microwave background," says Partridge, "because it is an absolute smoking gun for inflation. That is the holy grail. Whether Planck will see it or not is still an open question, but we're sure as hell going to be looking."



Planck's microwave detectors captured this striking image of cold dust in a region 30° wide toward the constellation Perseus. Red shows areas of lower frequency, which corresponds to a colder temperature. ESA/LFI & HFI CONSORTIA

Intervening matter



Mass warps space-time, and light will follow this warping. Thus, radiation from the early universe — like galaxies or the cosmic microwave background — will appear distorted once it reaches Earth. Scientists can use this "gravitational lensing" effect to learn about the universe's mass. *ASTRONOMY*: ROEN KELLY

SEE HOW THE PLANCK SPACECRAFT MAPS THE MICROWAVE SKY AT **www.Astronomy.com/toc.**

SOLAR BLEMISHES

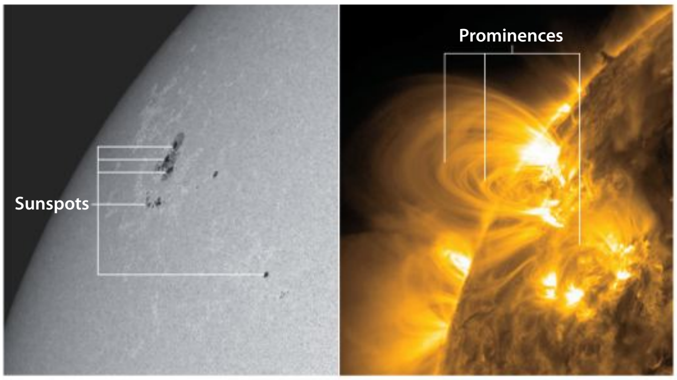
Q: WHY DO SUNSPOTS APPEAR IN GROUPS?

Shula Van Gilst, *Albuquerque, New Mexico*

A: Sunspots and their behavior are direct manifestations of the Sun's magnetic field, which we still don't fully understand. Here's what we do know: Extremely hot gas, called plasma, in the Sun's outer atmosphere rotates differentially — faster at the middle than at the poles — while plasma in the interior rotates as a solid body. The rotation of the charged solar plasma produces a current. This current creates a magnetic field like that of a bar magnet with a north pole and a south pole aligned with the axis of rotation, but the differences of rotation speed mean the magnetic field becomes wound up and tangled.

Loops, which are like the magnetic field from a horseshoe magnet embedded in the Sun's visible surface, push through this photosphere. The magnetic loops have a north polarity and a south polarity where they enter and exit the Sun — called "feet." If the magnetic field at the base of the loop is strong enough, it prevents the conveyor-belt-like transport of energy from the Sun's interior to the surface because charges cannot cross magnetic field lines. Without its main energy source, that region cools, forming sunspots.

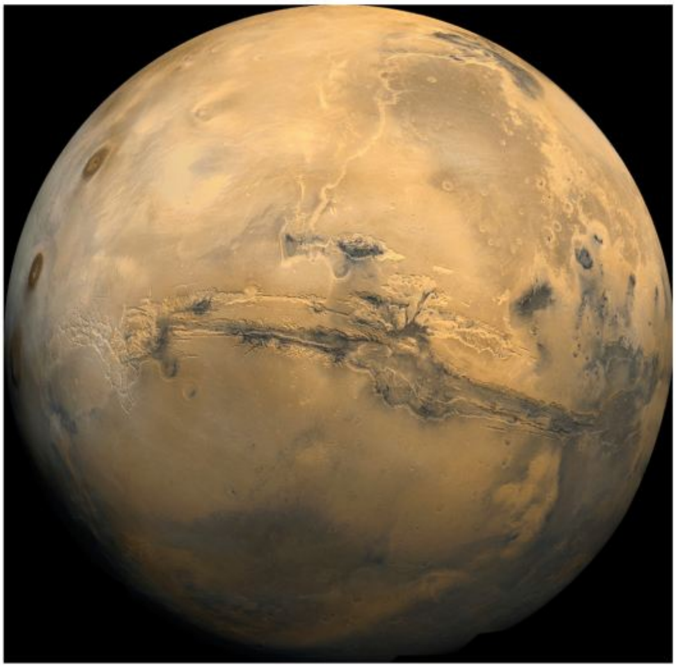
Based on this scenario, you might wonder instead why sunspots do not only appear in matched opposite-polarity pairs.



Sunspots are the exit and entrance points of magnetic loops on the solar surface. The magnetic fields suspend material in an arch of gas, called a prominence. Shown here are images through two filters to capture the sunspot groups and also the hot prominences arching between them. NASA/SDO

The turbulent motions in the Sun's interior fragment the loops in the solar magnetic field. Sunspots generally appear in opposite-polarity pairs or in opposite-polarity groups when the magnetic field is fractured. If one foot of the magnetic loop becomes too spread out, it may be too weak to form a sunspot, and the opposite-polarity sunspot will appear as an individual, but the ghost of its partner's magnetic field still remains. And sometimes the magnetic field can emerge to the surface fractured and tangled, leading to a great and confusing sunspot group. It is not surprising that in the turbulent environment of the Sun's atmosphere, the general rules that guide the way sunspots appear are often broken.

Sarah Jaeggli
Montana State University, Bozeman



Valles Marineris stretches across nearly one-fourth of the Red Planet's circumference. As Mars' 120-mile-thick (200 kilometers) lithosphere pulled apart, it created this giant canyon. NASA/NSSDC PHOTO GALLERY

Q: DO SCIENTISTS KNOW WHAT CAUSED VALLES MARINERIS ON MARS?

Frederick Castelot
Milford, Connecticut

A: Valles Marineris, the great canyon of Mars that stretches for more than 2,500 miles (4,000 kilometers) and is up to 4.3 miles (7.0km) deep, formed as the martian lithosphere spread apart early in the Red Planet's history. The lithosphere is the solid, uppermost portion of the planet that sits above the partly molten mantle. The martian lithosphere is approximately 120 miles (200km) thick — much thicker than Earth's. This cold lithosphere has a great deal of strength and can hold up the large martian volcanoes such as Olympus Mons.

As on Earth, the mantle of the Red Planet is slowly moving, or convecting, which produces stretching and pulling forces at the bottom of the lithosphere. On our planet, these forces are strong enough to break the lithosphere into plates that can move apart, creating continental drift and plate tectonics. On Mars, the lithosphere is too thick to be able to move great distances, but the mantle's force was strong enough to pull the lithosphere apart, creating the deep parallel canyons of Valles Marineris.

Phil Christensen
Arizona State University, Tempe

Q: HOW CAN SCIENTISTS DISTINGUISH BETWEEN PLANETARY NEBULAE AND SUPERNOVA REMNANTS?

Robert Nichols
Moretown, Vermont

A: Distinguishing between a planetary nebula and a supernova

remnant is not always straightforward because they often have similar shapes and sizes. However, the light that these two types of objects emit shows several differences, and we therefore often have to take a multiwavelength approach.

The fundamental physics going on is vastly different. A planetary nebula is created when a Sun-like star near the end of its life sheds its outer layers in a wind. The leftover central star then heats that material to temperatures of 10,000 to 20,000 kelvin. A supernova remnant results from the titanic explosion of an entire star, where the shock wave races into the surrounding medium at several thousand miles per second and heats the surrounding gas to millions of degrees.

Because of planetary nebulae's (relatively) low temperatures, they tend to emit a lot of optical light, which we can break into specific wavelengths that correspond to various elements, like oxygen (a particularly strong signal) and sulfur.

Supernova remnants, on the other hand, are often so hot that they emit X-rays instead of much optical radiation; this is because the elements are almost completely ionized (meaning, most of an atom's electrons have been knocked off the atom), and this material doesn't emit optical spectral lines. Old supernova remnants are cooler and thus can emit some optical radiation, but the ratios of the strengths of one spectral line to another (like sulfur to hydrogen) are different from those seen in planetary nebulae. A supernova remnant's X-ray radiation shows spectral lines from highly ionized, shock-heated elements like oxygen, neon, magnesium, iron, and silicon. Additionally, the extraordinarily hot gas gives off what we call "continuum X-ray emission." Some planetary nebulae can emit X-rays, but not as a result of shock-heated gas, and we can tell the difference between the processes.

We also see radio emission from planetary nebulae that results from protons and electrons recombining to produce radio spectral lines of hydrogen; this is called "thermal" emission. In supernova remnants, radio radiation is almost entirely "nonthermal," meaning that it comes from a small number of electrons that the supernova's shock wave has accelerated to extremely high energies far beyond those of the bulk of the electrons. Interestingly, we believe this process accounts for most of the cosmic rays in the galaxy. These are particles — electrons, protons, and other ions — that have incredibly high energies, millions of times higher than what we can make in our most powerful particle accelerators here on Earth.

Brian Williams
NASA's Goddard Space Flight Center, Greenbelt, Maryland

Q: WHAT EFFECT, IF ANY, DO THE OBJECTS IN THE KUIPER BELT AND OORT CLOUD HAVE ON THE ORBITS OR CHARACTERISTICS OF THE EIGHT MAJOR PLANETS?

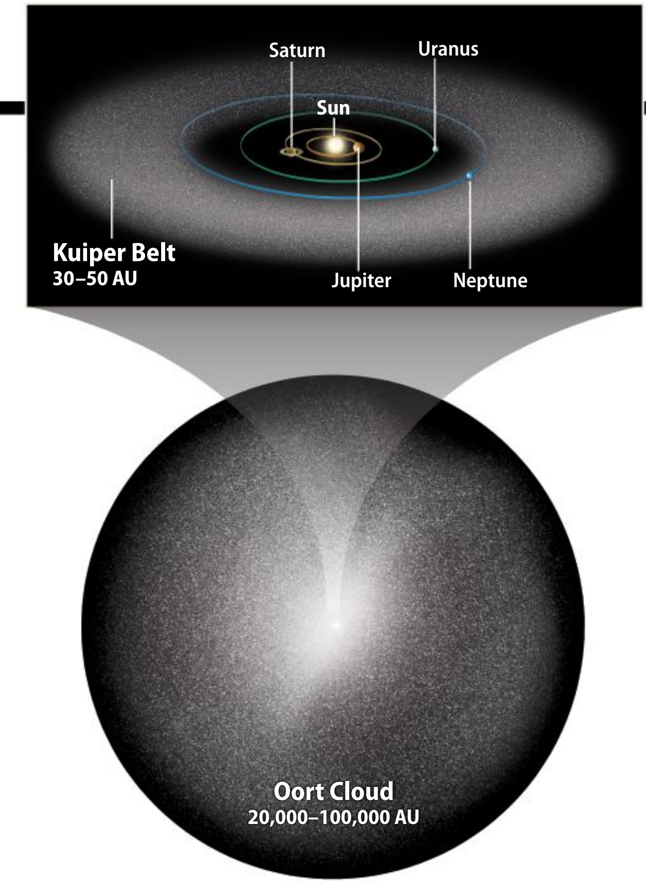
Jennifer Kroeker
Wichita, Kansas

A: Kuiper Belt and Oort Cloud objects can exert gravitational effects on the planets, but the real question is whether such perturbations are detectable. Based on the observation that long-period comets can appear in any part of the sky, we generally think that the Oort Cloud of comets is a near-spherical structure surrounding the solar system at a distance of about 20,000 to 100,000 astronomical units (AU, which is the average Earth-Sun distance) from our star. The nearly spherical nature of the cloud means that there would be no net gravitational effect on planetary orbits — all of the small gravitational pulls would cancel one another out.

On the other hand, the Kuiper Belt, located between 30 and 50 AU from the Sun, has a more flattened structure with a total mass of perhaps 0.1 that of Earth. In principle, the belt's characteristics would contribute to the precession of Neptune's orbit (i.e., rotation of the ellipse) of approximately 0.1 arcsecond per century, with correspondingly smaller effects on the planets closer to the Sun. To put this value in perspective, it is more than 400 times smaller than the anomalous precession of Mercury's orbit that results from general relativity; the effects are below the current level of detectability.

However, scientists have already detected the gravitational effects of the smaller members of the solar system on the orbit of a planet — analysis of radio ranging data with better than 12-meter accuracy obtained from the Viking landers on Mars between 1976 and 1981 enabled Myles Standish and Ron Hellings to estimate the masses of the asteroids Ceres, Pallas, and Vesta. In principle, the same could be done for Kuiper Belt objects if we had a sufficiently accurate signal source at a known location.

Carl Murray
Queen Mary University of London



The gravity of the Kuiper Belt has a small effect on Neptune's orbit and other solar system objects. The Oort Cloud, however, has a nearly spherical shape, so its overall gravitational pull likely cancels itself out. *ASTRONOMY*: ROEN KELLY

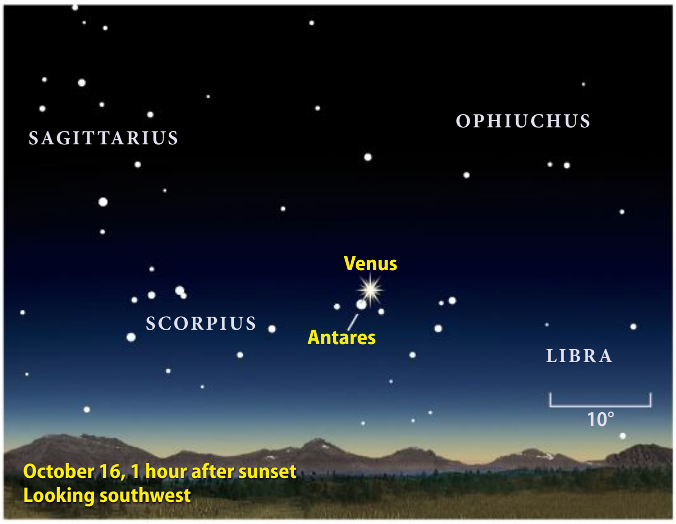
Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

MARTIN RATCLIFFE and ALISTER LING describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

October 2013: Uranus at its best



Brilliant Venus slides past 1st-magnitude Antares in mid-October. The two appear closest in evening twilight October 16. *ASTRONOMY*: ROEN KELLY

Most casual skygazers will spend October focusing their attentions on the early evening sky, where brilliant Venus holds court at dusk. It stands watch over two fainter planets, Mercury and Saturn, that struggle to shine through the bright twilight. Once darkness settles in, the subtler charms of Uranus come to the forefront. This distant ice-giant planet reaches opposition and peak visibility early in the month, when it remains on display all night.

More experienced observers likely will turn their eyes to the morning sky. There, a faint but brightening Comet ISON (C/2012 S1) could approach naked-eye visibility. If it does, this visitor from the solar system's depths will fuel anticipation of a spectacular show in November and December. But don't think ISON is the only predawn attraction — Mars and Jupiter both make bold appearances this month.

Our monthly tour of the night sky begins low in the western sky after sunset. **Mercury** reaches greatest elongation from the Sun on October 9, when it lies 25° east of our star. Unfortunately, the planet doesn't climb far above the horizon. From mid-northern latitudes, Mercury appears only 3° high in the west-southwest 30 minutes after sunset.

You can blame solar system geometry. In the Northern Hemisphere at this time of year, the ecliptic — the apparent path of the Sun across our sky — makes a shallow angle to the western horizon after sunset. Most of the 25° separation between the Sun and Mercury translates into distance along the horizon and not into altitude. Still, the planet shines brightly (magnitude –0.1) and should show up easily through binoculars if you have an unobstructed horizon.

Mercury doesn't ply the bright twilight alone this month. **Saturn** appears 5° north (to the upper right) of the innermost planet October 9 and 10. At magnitude 0.6, the ringed planet will be just as hard to see as its lower but brighter companion.

October 6 provides the best opportunity to view this planetary duo. From North America that evening, a 2-day-old Moon lies in the same vicinity. Mercury appears 2° south (lower left) of the thin crescent while Saturn perches 3° northeast (directly above) of the Moon. Both planets succumb to the Sun's glare during October's third week.

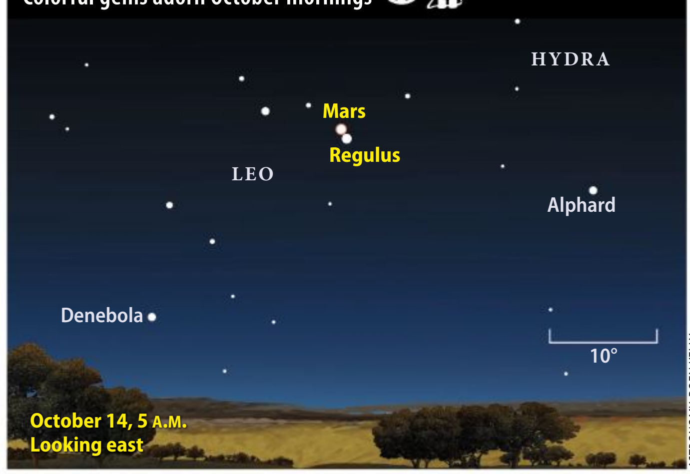
Venus dazzles low in the southwestern sky after sunset throughout October. It starts the month against the backdrop of Libra the Balance before crossing into Scorpius the Scorpion on October 7. That evening, the waxing crescent Moon lies 8° to Venus' right. The two appear 7° apart, with the Moon to the upper left, the following night.

On October 16, Venus passes 1.6° north of Scorpius' brightest star, 1st-magnitude Antares. At magnitude –4.4, the planet appears more than 100 times brighter than the star. Can you detect the color difference between the two objects? Venus reflects light from the slightly yellowish Sun whereas the red supergiant Antares shines with an orange hue. The pair stands 10° above the horizon 45 minutes after sunset.

You can track Venus' changing phase through a telescope of any size. On October 1, the planet appears distinctly gibbous, with 63 percent of its disk illuminated. By month's end, the phase has dwindled to half-lit. The planet's apparent diameter grows from 18" to 25" during the same period.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

Colorful gems adorn October mornings



Red meets blue in mid-October's predawn sky. Ruddy Mars and blue-white Regulus appear almost equally bright, though their colors set them apart. *ASTRONOMY*: ROEN KELLY

RISING**MOON**

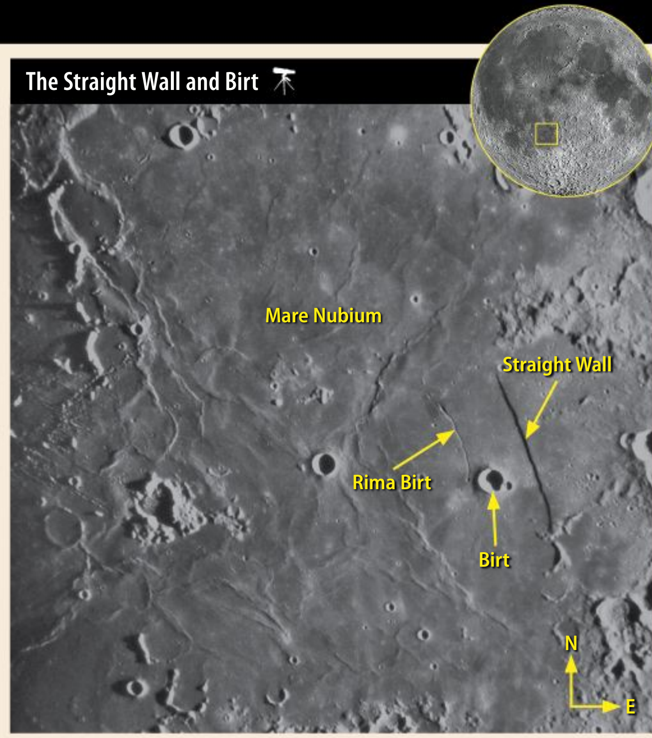
Scan a splendid scarp at sunrise

The Straight Wall is the Moon's best-known scarp. This near-side treasure takes the form of a long black blade that extends outward from its hilt. It lies in the southern third of the Moon and is perfectly placed on a relatively flat lava plain near the eastern shore of Mare Nubium. The Sun rises over this region just after First Quarter phase, on the evening of October 12.

Although its name conjures images of a cliff, the Straight Wall has a slope between 12° and 20° — a decent grade for driving but not steep enough for good tobogganing. Officially labeled as Rupes Recta in many lunar atlases, the Wall stretches about 70 miles long and rises some 1,300 feet above the plain. The scarp likely formed at the end of the period when lava flooded Mare Nubium, when the terrain sank and pulled westward away from the older terrain to the east. You'll see Mare Nubium better the following evening (October 13), once the Sun climbs higher in the lunar sky. By then, however, the shadows that make the Wall stand out will be gone.

The length of the shadows on the 12th, longer than those in the photo at right, should bring Rima Birt into view. This intriguing wormlike channel extends north from the 11-mile-wide crater Birt. To best see this groove, use high power and practice patience.

The Straight Wall and Birt



The modest slope of the Straight Wall appears more like a cliff under the low-angle illumination of a rising Sun one day past First Quarter.

Once darkness falls, shift your gaze to the opposite part of the sky to hunt for **Neptune**. The Roman god of the sea spends October wading across the cosmic ocean formed by the background stars of Aquarius the Water-bearer. This constellation appears in the southeast in early evening at midmonth and peaks in the south around 10 P.M. local daylight time.

During October's first week, you can find Neptune midway between two 5th-magnitude stars: Sigma (σ) and 38 Aquarii. By the 31st, the planet's slow westward drift has carried it noticeably closer to 38 Aqr.

You'll need binoculars to see Neptune, which, at magnitude 7.8, glows roughly 10 times fainter than its neighbors. A telescope at high power reveals the planet's 2.3"-diameter disk and subtle blue-gray color.

— Continued on page 42

METEORWATCH

A bullish forecast for October meteors

Traditionally, the Orionid meteor shower ranks as October's top display. But this year, the shower peaks October 21, when a gibbous Moon shares the predawn sky. Its presence washes out fainter meteors and diminishes the impact of brighter ones.

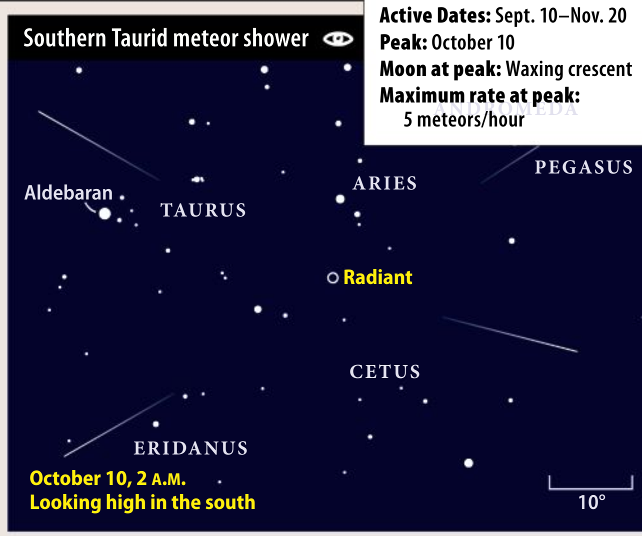
But October offers another shower, called the Southern Taurids, which peaks before dawn on the 10th. The crescent Moon sets the previous evening. The radiant — the point from where the meteors appear to emanate — climbs highest in the south around 2 A.M., when observers can expect to see up to 5 meteors per hour.

This radiant traverses an area of sky roughly 20° by 10° and, despite the shower's name, lies in the northern part of Cetus at the time of the peak. Southern Taurid meteors tend to be bright and move more slowly than typical meteors, which make them good subjects for imaging as well as naked-eye viewing.

Southern Taurid meteors

Active Dates: Sept. 10–Nov. 20
Peak: October 10
Moon at peak: Waxing crescent
Maximum rate at peak: 5 meteors/hour

Southern Taurid meteor shower



Relatively slow and often bright, the meteors of the Southern Taurid shower should put on a nice display October 10 under a Moon-free sky.

OBSERVING HIGHLIGHT Northern Hemisphere observers at dark sites should look for the zodiacal light before dawn approximately October 3–16.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

Planets are shown at midmonth

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

OCTOBER 2013

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

1 The Moon passes 7° south of Mars, 2 A.M. EDT

3 Uranus is at opposition, 10 A.M. EDT

SPECIAL OBSERVING DATE

3 Uranus reaches its 2013 peak, shining at magnitude 5.7 and appearing 3.7" across through a telescope.

4 New Moon occurs at 8:35 P.M. EDT

6 The Moon passes 3° north of Mercury, 6 P.M. EDT

The Moon passes 1.9° south of Saturn, midnight EDT

8 The Moon passes 5° north of Venus, 8 A.M. EDT

9 Mercury is at greatest eastern elongation (25°), 6 A.M. EDT

10 Southern Taurid meteor shower peaks

Mercury passes 5° south of Saturn, 3 P.M. EDT

The Moon is at perigee (229,792 miles from Earth), 7:14 P.M. EDT

11 First Quarter Moon occurs at 7:02 P.M. EDT

12 The Moon passes 0.9° south of asteroid Juno, 10 P.M. EDT

14 Mars passes 1.0° north of Regulus, 6 P.M. EDT

15 The Moon passes 6° north of Neptune, 2 A.M. EDT

16 Venus passes 1.6° north of Antares, noon EDT

17 The Moon passes 3° north of Uranus, 5 P.M. EDT

18 Full Moon occurs at 7:38 P.M. EDT; penumbral lunar eclipse

21 Orionid meteor shower peaks

Mercury is stationary, 11 A.M. EDT

25 The Moon is at apogee (251,380 miles from Earth), 10:24 A.M. EDT

The Moon passes 5° south of Jupiter, 6 P.M. EDT

26 Last Quarter Moon occurs at 7:40 P.M. EDT

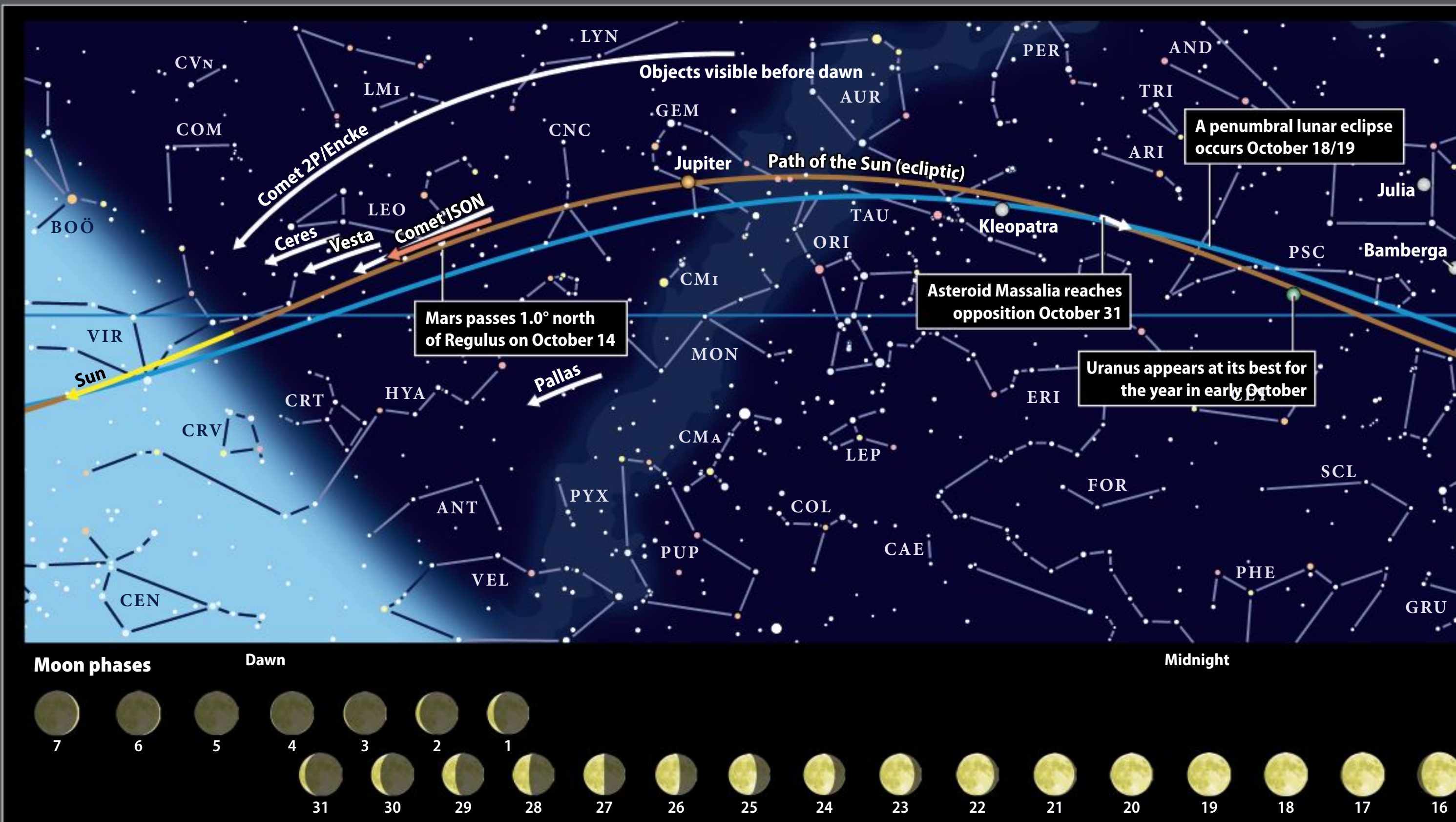
29 The Moon passes 6° south of Mars, 9 P.M. EDT

31 Asteroid Massalia is at opposition, 7 P.M. EDT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT www.Astronomy.com/starchart.

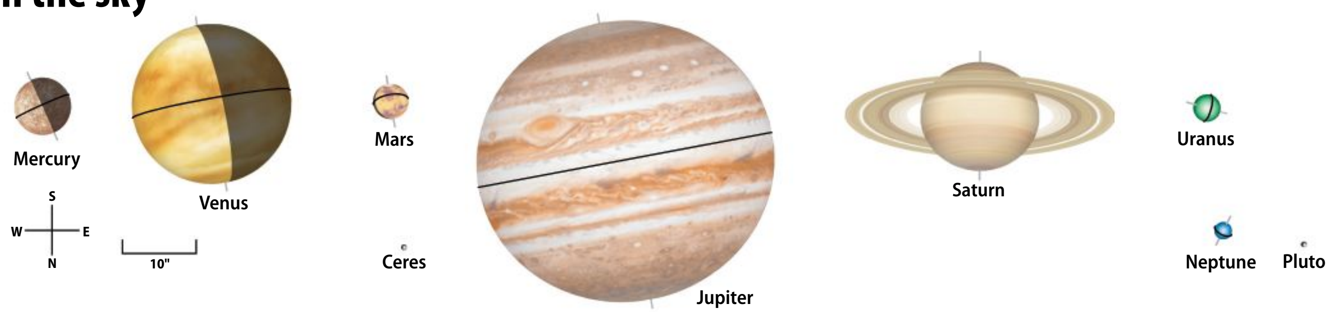
PATH OF THE PLANETS

The planets in October 2013



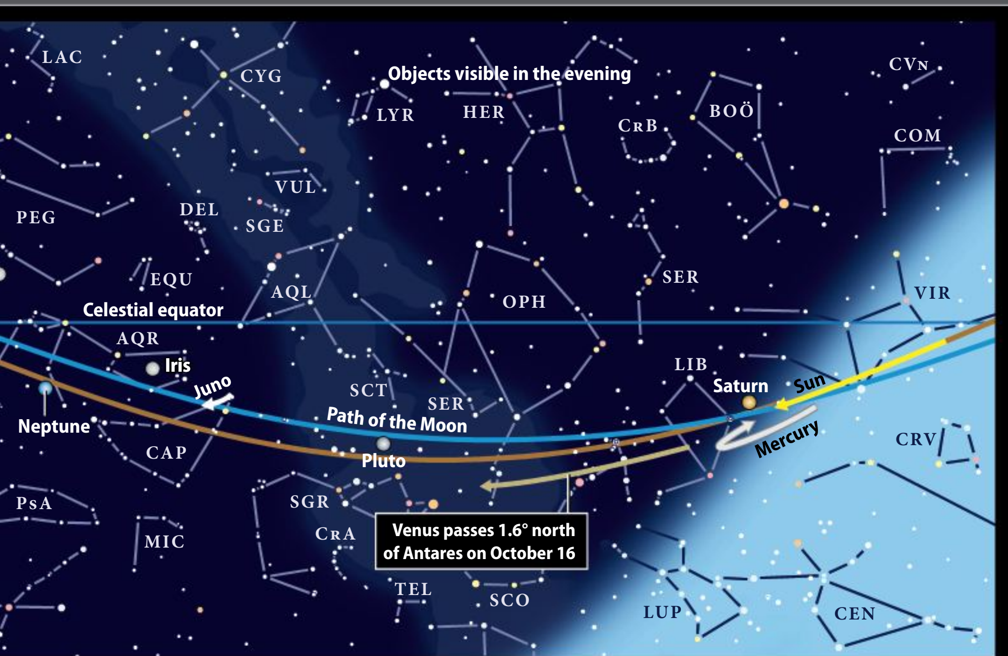
The planets in the sky

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



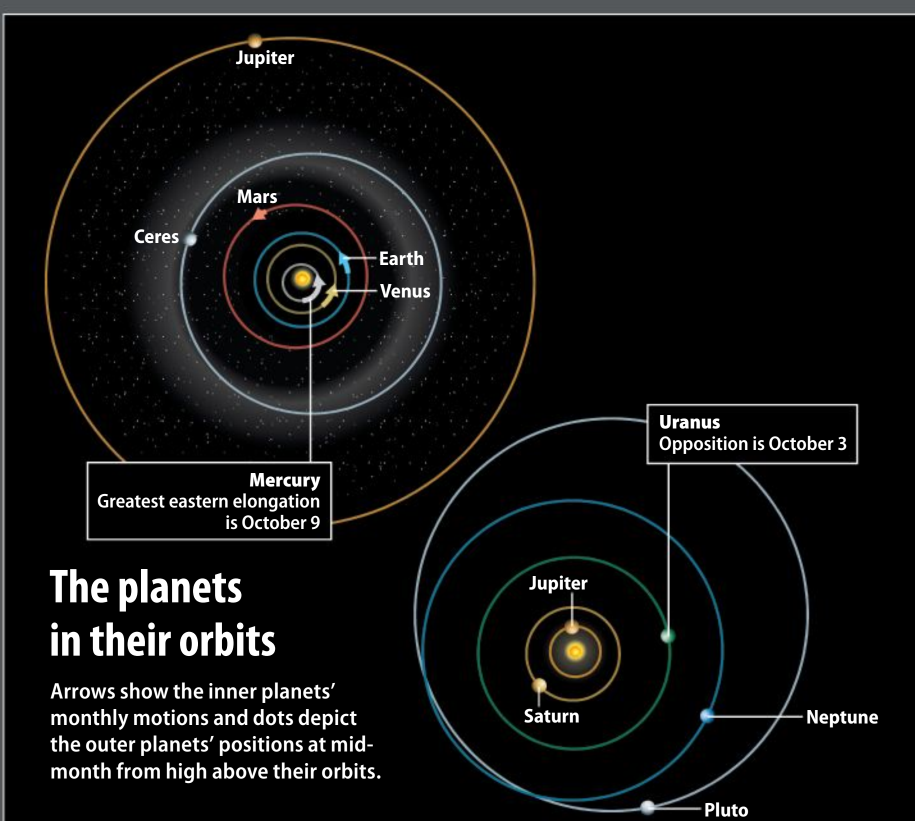
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 1	Oct. 15	Oct. 15	Oct. 15
Magnitude	0.0	–4.4	1.6	8.8	–2.3	0.6	5.7	7.8	14.1
Angular size	7.5"	20.9"	4.6"	0.4"	39.2"	15.5"	3.7"	2.3"	0.1"
Illumination	49%	58%	94%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.901	0.799	2.046	3.358	5.029	10.693	19.062	29.318	32.730
Distance (AU) from Sun	0.413	0.728	1.635	2.559	5.163	9.860	20.040	29.982	32.526
Right ascension (2000.0)	14h49.8m	16h21.7m	10h08.6m	11h40.7m	7h24.1m	14h32.5m	0h37.4m	22h19.3m	18h38.1m
Declination (2000.0)	–19°40'	–24°31'	12°57'	10°43'	21°59'	–12°42'	3°15'	–11°11'	–20°12'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



Early evening

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

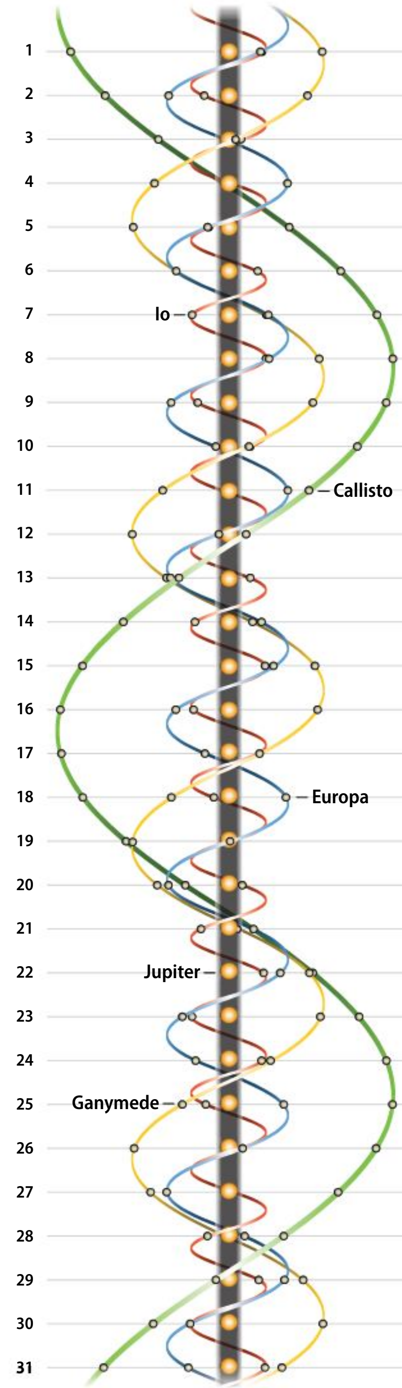


The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

Jupiter's moons

Dots display positions of Galilean satellites at 5 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Jupiter (northeast)	Mars (east)
Venus (southwest)	Uranus (south)	Jupiter (southeast)
Saturn (west)	Neptune (southwest)	Uranus (west)
Uranus (east)		
Neptune (southeast)		

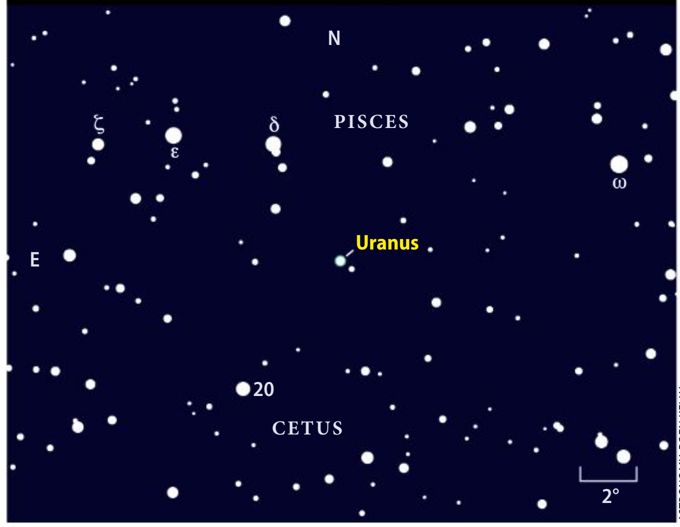
Head one constellation east of Aquarius, and you'll be swimming among the stars of Pisces the Fish, the 2013 home of **Uranus**. This world lies opposite the Sun in our sky October 3, when it shines brightest (magnitude 5.7), appears largest through a telescope (3.7" across), and remains visible throughout the night. It hangs low in the eastern sky as darkness falls and climbs highest in the south shortly after midnight local daylight time.

Although Uranus appears bright enough to see with naked eyes from a dark site, binoculars make the job of finding it easier. You'll need to target a sparse region near the border between Pisces and Cetus. First, find Delta (δ) and Epsilon (ε) Piscium, a pair of 4th-magnitude stars separated by 3.5°. At opposition, Uranus lies 4.8° southwest of Delta. The space between the two grows to 5.7° by month's end. Point a telescope at the planet to see its distinctly blue-green disk. For more details on observing Uranus, Neptune, and their faint moons, see "Prime time for Neptune and Uranus" in the August *Astronomy*.

Jupiter rises shortly after midnight local daylight time October 1 and in late evening by midmonth. The strikingly bright object resides high in the southeast by the time twilight commences. The planet appears against the backdrop of Gemini the Twins, a bit less than 10° southwest of that constellation's brightest star, 1st-magnitude Pollux. At magnitude –2.3, however, Jupiter outshines the star by 25 times. On October 4, the giant planet passes 0.1° due north of magnitude 3.5 Delta Geminorum.

When viewed through a telescope, Jupiter's disk measures 39" across the equator and displays a vast wealth of

An ice giant reaches its peak



Spy Uranus with naked eyes or binoculars among the stars of Pisces near its October 3 opposition. A telescope shows this world's blue-green color.

COMETSEARCH

Autumn's bright visitor begins its show

The comet we've been waiting a year for is finally nearing its peak. Although our best views of ISON (C/2012 S1) will come in November and December, October should see it brighten to within the range of small telescopes and binoculars under a dark sky by month's end. ISON lies in the east before dawn, where its path glides almost parallel to bright Mars. Avoid observing from sites east of a city so you won't have to look through a veil of light pollution.

Any scope at low power should show that ISON is not a galaxy. Compare and contrast it with the nearby spirals M95 and M96. (The comet passes just south of this pair October 25.) Can you see ISON grow brighter week by week, as it should?

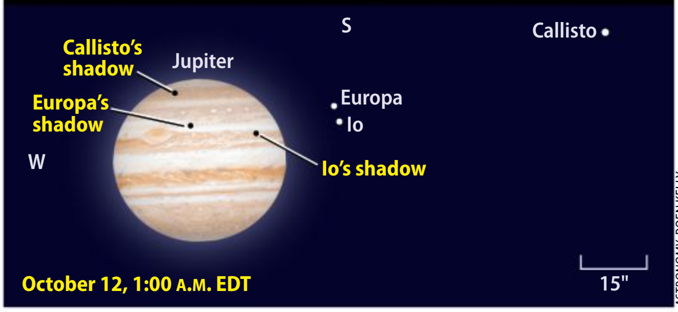
At medium magnification, notice how the galaxies have a mildly elliptical shape. Each shows a nearly pointlike core surrounded by a dimmer inner region wrapped in a halo that fades out quite uniformly. ISON's light drops off, too, but in a much different way. The comet's interaction with the solar wind and radiation compresses the eastern side into a fairly sharp boundary while the western flank appears noticeably more diffuse. Earth's current position gives us a view of the comet halfway between edge-on and broadside, which means that the northern edge should appear sharp.

Now push the power up to 150x or more, and look for details in the comet's core. Its true surface — the "dirty snowball" that creates the whole show — lies hidden beneath layers of dust. The nearly point source that glows brightly in the middle of the comet's head is the so-called false nucleus. Also look for any elongation or uneven shading in the core. It might be a month early for ISON to display these characteristics, but it doesn't hurt to look.

Comet ISON (C/2012 S1)

Hubble took this image of ISON on April 10, when it was nearly 400 million miles from Earth. The comet will shine much brighter during October.

Rare triple shadow transit on Jupiter



The colorful disk of the solar system's largest planet hosts the shadows of three Galilean moons for 65 minutes the night of October 11/12.

atmospheric detail. Two dark belts, one on either side of a bright equatorial zone, show up through nearly any instrument. On mornings with good seeing conditions, larger scopes reveal a series of alternating belts and zones.

Jupiter's four bright moons prove equally fascinating. Any telescope will show their elegant dance moves, all choreographed by Kepler's laws of orbital motion.

Occasionally, these moves produce dramatic changes in a few hours. Target Jupiter the morning of October 10. At around 3 A.M. EDT, Io and Ganymede both appear east of the planet, with Io east of its sibling. The inner moon catches up with Ganymede by 7 A.M. EDT (around dawn on the East Coast), however, and starts to transit the giant world before its neighbor.

An even more impressive, and certainly rarer, dance takes place two nights later when the shadows of three Galilean satellites appear on Jupiter's disk simultaneously. How rare is this? The next such triple shadow transit will take place June 3, 2014, and the one after that on January 24, 2015 — but you'll have to wait until 2032 to see another.

Callisto's shadow appears on Jupiter's disk starting at 11:12 P.M. EDT October 11, followed by Europa's shadow at 11:24 P.M. and then Io's shadow at 12:32 A.M. All three black dots pock the jovian cloud tops until Callisto's shadow lifts back into space at 1:37 A.M. Io's leaves next, at 1:48 A.M., while Europa is the last shadow standing until 2:01 A.M.

Several hours after Jupiter appears on the scene, **Mars** pokes above the eastern horizon. The Red Planet rises around 3 A.M. local daylight time October 1 and a half-hour earlier by month's end. Glowing at magnitude 1.6, Mars appears slightly fainter than nearby Regulus, Leo the Lion's brightest star. It will be easier to tell the two apart by their colors: The planet appears orange-red while the star has a slight bluish cast.

The eastward motion of Mars relative to the background stars carries it 1° north of Regulus on October 14. By October 31, Mars stands 2° south of M95 and M96, a pair of spiral galaxies in south-central Leo.

But Mars' most impressive companion has to be **Comet ISON** (C/2012 S1). The two track together across the morning sky during the first half of October. On the 1st, the comet lies 2° north of Mars; the gap narrows to 1° by the 15th. Astronomers expect ISON to be within the range of small telescopes in early October and binoculars by month's end. It may even approach naked-eye visibility under the darkest skies.

The comet's brightness during October will be an important harbinger of things to come. If ISON falls well behind what astronomers are predicting for this month, the projected spectacle in November and December could evaporate as quickly as the ices on its nucleus. (Yes, we know the ices actually sublimate and don't evaporate.) For complete observing information on this icy visitor, see "Comet ISON brightens before dawn" on p. 50.

LOCATING**ASTEROIDS**

Catch an eccentric asteroid while you can

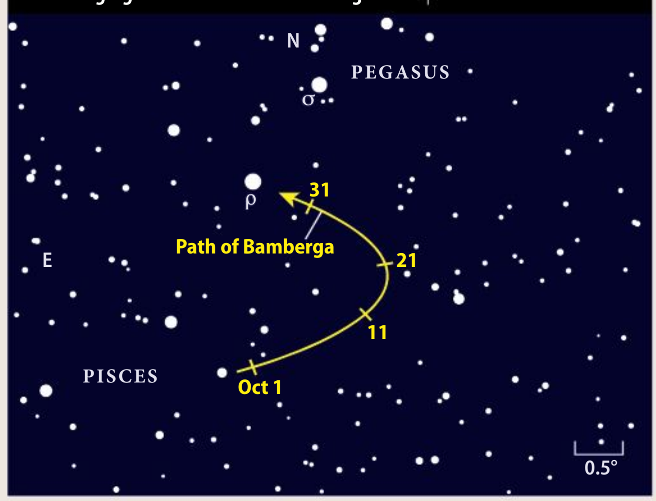
Competitive stargazing may not be common, but most amateur astronomers enjoy making observing lists and chalking up records of unusual sights. October offers you a chance to bag one of the latter: the high-numbered asteroid 324 Bamberga. Because the numbers reflect their order of discovery, and astronomers typically find bright objects before dim ones, we rarely feature asteroids with numbers greater than 30.

Start your search at the Great Square of Pegasus, which lies more than halfway up in the southeast at mid-evening. Imagine the Square as a giant clock with the lower right corner at the center and the upper right corner marking the big hand at 12. Our guide star for Bamberga is 5th-magnitude Rho (ρ) Pegasi, which lies where the small hand would point to 5 o'clock. The asteroid remains within 2° of Rho all month.

Few background stars here glow as bright as the magnitude 8.5 asteroid, so you should be able to identify the dot. Return to the same region another night to confirm that the object has moved and thus is the asteroid. Austrian astronomer Johann Palisa used this systematic approach to discover Bamberga in 1892.

Bamberga orbits on a highly elongated path — only six of the first 500 asteroids have orbits that deviate more from a circle. Although it completes a circuit of the Sun every 4.4 years, the geometry delivers a close approach to Earth only every fifth cycle. So, we likely won't be featuring Bamberga again until 2035.

Bamberga glides from Pisces into Pegasus



The 9th-magnitude asteroid 324 Bamberga stays within 2° of the 5th-magnitude star Rho (ρ) Pegasi throughout October. *ASTRONOMY*: ROEN KELLY

Celestial snowballs

What makes a

Slight tweaks in the celestial recipe make a good comet great.

by Joseph Marcus

Great Comets, the kind that deserve capitalization, are rare. These icy, dusty visitors to the inner solar system become members of this highest class if they dazzle casual skywatchers. Until almost the 20th century, civilizations thought that comets — the only easily visible celestial objects to appear suddenly and then disappear — foretold doom, destruction, and the births and deaths of important leaders. Great Comets awed and terrorized, as Halley's Comet did during its A.D. 1066 appearance. Those in England believed it portended King Harold II's death in the Battle of Hastings, though if they took the glass-half-full viewpoint, they could have said it instead foretold William the Conqueror's victory over King Harold II. The greatest of the Great Comets may be so bright that they cast shadows at night, as Comet Tebbutt (C/1861 J1) did, or become visible in broad daylight even to casual observers, like the Great March Comet (C/1843 D1) did.

With Comet ISON (C/2012 S1) about to appear, scientists and casual observers alike are beginning to wonder if it will join the elite ranks of the Greats. Now is a good time, then, to ask: What exactly makes a comet "Great"?

The short answer is "brightness." But what makes some comets so much brighter than their peers? After all, comets are

Joseph Marcus *is a surgical pathologist by day and comet aficionado by night.*

Great Comet?

Comet McNaught (C/2006 P1) was visible from the European Southern Observatory's Paranal Observatory when it came close to the Sun in January 2007. The bands in its impressive tail are called "striae." ESO/PARANAL OBSERVATORY

cooked up using the same general recipe — a little ice, a little dirt, a little rock, and long orbits that eventually bring them near the Sun. Some, however, clearly outshine others.

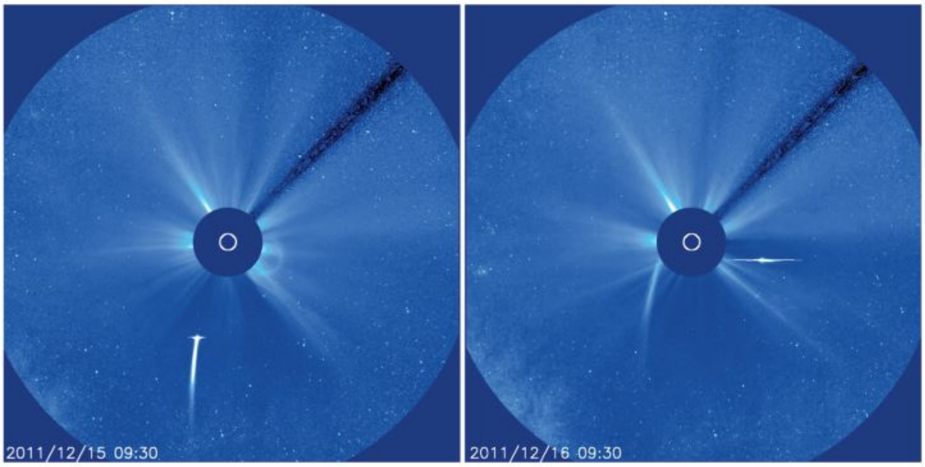
The ingredients that work together to create any comet's appearance are its absolute magnitude, its distance from the Sun, its distance from Earth, and its scattering angle, which relates to the comet-Earth-Sun configuration. Changing any of these elements changes a comet's brightness — in the cases of Great Comets, for the better.

Cometary ingredients

ABSOLUTE MAGNITUDE. Some comets come closer to Earth than others, causing them to appear brighter, so astronomers have to level the playing field. A comet's absolute magnitude represents how bright the comet would look if placed 1 astronomical unit (AU) from the Sun and Earth. (An AU is the distance between Earth and the Sun, or approximately 93 million miles [150 million kilometers].)

Comets' absolute magnitudes range from fainter than magnitude 12 into the negative magnitudes. The value relates to the size and active area of the nucleus — in other words, what stuff and how much of it make up the comet. Nuclei vary from several dozen feet to a few miles across, and they all have unique compositions of dust and ice mapped differently across their bodies. We see comets because they heat up as they approach the Sun, causing the release of dust particles and volatiles into the coma in a process called "outgassing." The dust reflects and scatters sunlight, while some sunlight-stimulated gases eject photons through fluorescence. The reflected and fluoresced photons combine into a comet's inherent brightness.

SUN DISTANCE. The Sun kicks up a comet's dust and gas, whatever the components and arrangement of that material are. The more intense the Sun's light and heat, the more gas and dust they liberate from the icy nucleus. If a comet comes twice as close to



The Solar and Heliophysics Observatory (SOHO) snapped these shots of Comet Lovejoy (C/2011 W3) rocketing toward then Sun (left) and then around its other side just a day later. This comet is member of the Kreutz sungrazer family, objects that came from a broken-up larger comet. The tail, material blown back by the solar wind, always points away from the star. NASA/SOHO

the star, it is four times as influenced; if it comes four times as close, it is 16 times as affected — this relationship is called the "inverse-square law." It applies doubly to comets: The sunlight that reflects off the shed cometary material also obeys the inverse-square law. So when a comet is twice as near to the Sun, it reflects four times as much sunlight. The combined effects of a comet's proximity to the Sun mean that if its distance is halved, it theoretically is 16 times as luminous. In practice, though, it will be more like eight to 10 times as vivid on average. The closest a comet comes to the solar system's great radiator is called its "perihelion distance," and the smaller that number, the longer and more impressive the comet's tail.

The comets that venture closest receive a third brightness boost because of their sodium, which releases yellow-orange light when energy excites it. If a comet comes within 18.5 million miles (30 million km) of the Sun, sodium photons dominate its visible light output. At 14 million miles (22.5 million km), this atomic fluorescence kicks a comet's brilliance up by nearly two magnitudes. There is a limit, however: If a comet ventures closer than around 4.6 million miles (7.4 million km) to the Sun — six times as close as Mercury goes — brightness drops off because silicate, or rocky, grains in the coma begin to evaporate and shrink under the increasingly intense solar heat.

EARTH DISTANCE. A galaxy can be billions of times as intrinsically bright as the Sun, but because it is located billions of light-years away, it is not even visible to the unaided eye. Likewise, a comet's greatness depends partly on where it is in relation to Earth, our telescopes, and our eyes. If it comes two times closer, it appears four times brighter.

SCATTERING ANGLE. Sunlight bounces off the microscopic dust in a comet's coma — the envelope of material around the nucleus — and in its tail. These particles scatter sunlight preferentially and strongly in the direction of the sunlight's travel, a phenomenon termed "forward scattering." When a comet ventures between Earth and the Sun, such scattering enhances its brightness many times over as particles redirect light toward earthbound observers. The smaller the scattering angle, the more forward scattering boosts its brightness.

Infrared astronomers Edward Ney and Kenneth Michael Merrill first quantified this effect in Comet West (C/1975 V1). They found that a scattering angle of 33° (see "How forward scattering brightens a comet" on p. 47) made the comet appear nine times (2.4 magnitudes) brighter than it did at an angle of 97°. If a comet were at or near 0°, it could brighten by an incredible 1,000- to 2,000-fold — an average of eight full magnitudes — compared to how it would look at a 90° side-angle view. But when the scattering angle is small, the comet appears close to the Sun in the sky — it's up during the day and our star's glare can drown out its light. But its added brightness then is so extreme that it can burst into visibility in the mid afternoon, sometimes jumping up to "Great" status.

Using these four ingredients, plus a few extra bonuses, we can "score" comets and objectively determine which are the greatest of the Great.

A "scorecard" for Great Comets

How do we rate a Great Comet? That's hard! Beauty is in the eyes of beholders, and all beholders will argue passionately for one comet over another. To complicate matters, even Great Comets can be elusive. For instance, Comet Ikeya-Seki (C/1965 S1) was a Great Comet, but few people viewed it at its best, leading Donald D. Zahner, the editor of the old *Review of Popular Astronomy*, to wag, "Undoubtedly, Comet Ikeya-Seki will rank as the brightest and most spectacular comet that amateur astronomers have never seen!"

To sidestep such thorny aesthetic and philosophical issues, we will be practical and objective. In the spirit of baseball, let's "score" Great Comets based on the four ingredients of comet brightness. We will base a comet's "points" on magnitude — one point for each magnitude gained from having a brighter absolute magnitude, coming closer to Earth, going closer to the Sun, and broaching smaller scattering angles.

For reference, an object that is one magnitude brighter than another is 2.5 times as bright; an object two magnitudes brighter is 2.5 × 2.5 (6.25) times as bright. Three magnitudes? 2.5 × 2.5 × 2.5, or 15.625 times as brilliant. Thus, each increase of one point represents a 2.5-fold change in the comet's luminance.

Let's throw in some additional points if a comet goes into "extra innings" by remaining visible to the naked eye for more than 40 days (one point), 100 days (two points), or 250 days (three points).

The comet's total score is the sum of the points across the five categories.

The Deep Impact probe captured this image of Comet 9P/Tempel's nucleus just before it crashed into the surface, kicking up dust and ice whose composition scientists then could analyze. NASA/JPL-CALTECH

Ground rules for the game

1 A comet must have been visible to the unaided eye to earn any points.

2 We score a comet based on its qualities when it appeared brightest: the values for Earth-comet distance, comet-Sun distance, and scattering angle that, in combination, produced its peak brilliance from Earth's perspective — its greatest visible magnitude.

3 There is nothing grander than a daylight comet. But for such an object to be scored on its noonday qualities, it must have been readily visible to the naked eye. That criterion disqualifies Hale-Bopp's (C/1995 O1) daytime values, as it was observed only with instruments while it was light out, and Comet West (C/1975 V1), which was a challenge to see unaided in the daytime.

4 The tail does not enter directly into consideration in the scoring system. Its length and intensity are embedded indirectly in the other scoring parameters.

5 To be considered Great, a comet must score nine or more points.

The scoring system that starts below surely is imperfect, but at least it is something to work with. Let's play ball!

NAKED-EYE VISIBILITY IN DAYS	PTS
0–40	0
41–100	1
101–250	2
> 250	3

ABSOLUTE MAGNITUDE	PTS
≥ 6	0
5.0–5.9	1
4.0–4.9	2
3.0–3.9	3
2.0–2.9	4
1.0–1.9	5
0.0–0.9	6
–0.1–(–0.9)	7
≤ –1.0	8

EARTH DISTANCE (AU)	PTS
> 1.000	0
0.632–1.000	1
0.399–0.631	2
0.252–0.398	3
0.159–0.251	4
0.101–0.158	5
0.064–0.100	6
0.041–0.063	7
0.026–0.040	8
0.017–0.025	9
0.011–0.016	10
0.007–0.010	11

SCATTERING ANGLE (°)	PTS
> 90	0
58–90	1
41–57	2
29–40	3
21–28	4
15–20	5
10–14	6
6–9	7
2–5	8
< 2	9

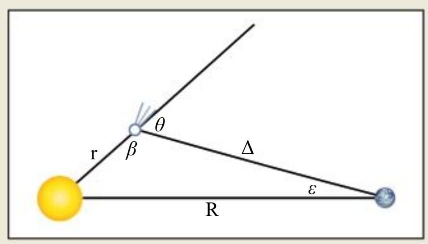
SUN DISTANCE (AU)	PTS
> 1.000	0
0.757–1.000	1
0.572–0.756	2
0.433–0.571	3
0.327–0.432	4
0.248–0.326	5
0.187–0.247	6
0.142–0.186	7
0.108–0.141	8
0.081–0.107	9
0.062–0.080	10
0.047–0.061	11

HOW FORWARD SCATTERING BRIGHTENS A COMET

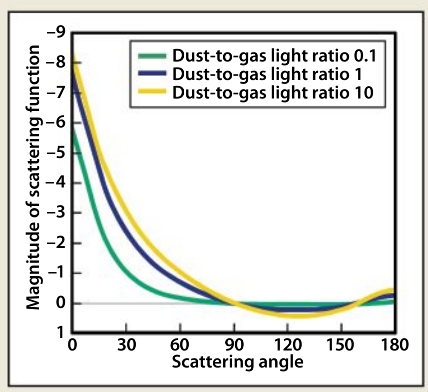
A phenomenon called "forward scattering" can enhance a comet's brightness. When the Sun's light hits the dust and ice particles in the coma, it is not reflected back in a straight line. Instead, it is scattered in different directions. The particles scatter the light most in the direction of the sunlight's travel — forward. If Earth is in the forward direction, observers will see extra light. The degree to which forward scattering boosts brightness depends on the scattering angle (θ), which relates to how Earth, the Sun, and the comet are oriented, as shown below in the topmost diagram. You can determine the scattering angle by subtracting the more familiar "phase angle" (β) from 180°. The smaller the angle, the more forward-scattered light will shoot back toward Earth, heightening the comet's brilliance.

Geometry isn't the only factor determining scattering's effects. Comets' own compositions have an influence, too. If a comet is dustier than it is gassy, it releases relatively more particles from which the light can bounce, so dust-heavy comets receive the best forward-scattering enhancements. Even "gassy" comets, though, have impressive boosts at small scattering angles.

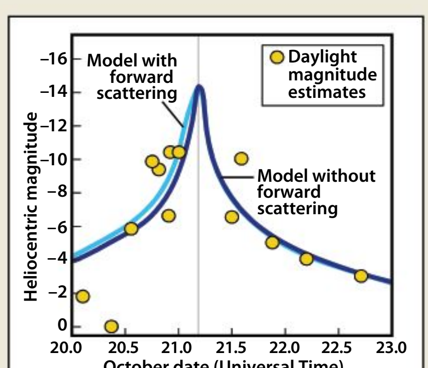
Forward scattering is a significant ingredient in many Great Comets, but the geometry that makes the scattering angle less than 90° is uncommon. Eighteen of the 20 illustrious comets featured in the next pages ventured into this unusual kind of configuration. Ten reached scattering angles of 36° or less, which, according to my model, brightened them by two or more magnitudes. — *J. M.*



The scattering angle (θ) determines how much forward scattering brightens the comet. The closer θ is to 0°, the brighter the comet will appear. *ASTRONOMY:* ROEN KELLY, AFTER JOSEPH MARCUS



Forward-scattering effects depend on how much of a comet's light comes from its gas compared to its dust. This plot shows the differences between "average" comets (blue), those whose light is mostly from dust (yellow), and those whose light is mostly from gas (green). The phenomenon preferentially affects dusty comets. *ASTRONOMY:* ROEN KELLY, AFTER JOSEPH MARCUS



Comet Ikeya-Seki (C/1965 S1), visible in daylight, was nearly as bright as the Full Moon. Background fluorescence from sodium boosted its brilliance the most, blunting the forward-scattering effects. *ASTRONOMY:* ROEN KELLY, AFTER JOSEPH MARCUS

The greatest comets of the 19th, 20th, and 21st centuries

	C/1811 F1	C/1819 N1	1P (1835)	C/1843 D1	C/1858 L1	C/1861 J1	C/1865 B1	C/1874 H1	C/1881 K1
DAYS VISIBLE	3 (260)	0 (<30)	2 (187)	1(48)	1 (80)	2 (104)	0 (36)	1 (50)	2 (130)
ABSOLUTE MAGNITUDE	6 (0.0)	2 (4.0)	2 (4.3)	2 (4.2)	3 (3.3)	3 (3.9)	3 (3.8)	1 (5.7)	2 (4.1)
SUN DISTANCE (AU)	0 (1.174)	4 (0.358)	1 (0.880)	10 (0.069)	2 (0.617)	1 (0.894)	6 (0.200)	2 (0.689)	2 (0.744)
EARTH DISTANCE (AU)	0 (1.221)	1 (0.765)	4 (0.187)	1 (0.934)	2 (0.539)	5 (0.133)	1 (0.960)	3 (0.351)	3 (0.293)
SCATTERING ANGLE (°)	0 (>90)	2 (54)	1 (66)	3 (36)	1 (61)	4 (23)	1 (89)	3 (32)	4 (26)
TOTAL	9	9	10	17	9	15	11	10	13

C/1882 R1

SOUTH AFRICAN ASTRONOMICAL OBSERVATORY

The **Great September Comet (C/1882 R1)** was the granddaddy of them all. With an absolute magnitude of 0.8, which is as bright as the star Betelgeuse, it scores highest on our list. Observers W. H. Finlay and W. L. Elkin followed it in daylight all the way to the limb of the Sun, when its scattering angle was just 18°. It developed a massive tail and was visible without optical aid for over four months.

C/1843 D1

The **Great March Comet of 1843 (C/1843 D1)** was "a very beautiful star" 2.1° from the Sun in daylight. As it moved into the evening sky in March, its bright, narrow tail — "like a flow of fire from a furnace," according to Canadian-American astronomer James Craig Watson's account in *A Popular Treatise on Comets* (1861) — measured up to 60° long across the sky. UNIVERSITY OF CALIFORNIA DIGITAL LIBRARY

C/1861 J1

BILDERATLAS DER STERNENWEL

Observers had seen **Comet Tebbutt (C/1861 J1)** in the Southern Hemisphere for several weeks when it suddenly appeared in the northern skies, gobsmacking Europeans, after it passed between Earth and the Sun. German astronomer J. F. Julius Schmidt saw the brilliant tail cast shadows on the wall of the Athens Observatory. The comet then was only 12.3 million miles (19.9 million km) from Earth. The combined magnitude from the coma's inherent brightness, the tail's brightness, and the forward-scattering lift was –6.5. John Tebbutt, an Australian astronomer, discovered this Great Comet of 1861, as well as the **Great Comet of 1881 (C/1881 K1)**.

C/1965 S1

ROGER LYNDS/NOAO/AURA/NSF

Comet Ikeya-Seki (C/1965 S1) was visible in daylight near the Sun for two and a half days, becoming nearly as bright as the Full Moon. Its bright, narrow tail amazed viewers and photographers in October 1965 after its perihelion passage.

The recent comet **Lovejoy (C/2011 W3**) does not make the list — its absolute magnitude of 10 was too dim. However, comet scientists Zdenek Sekanina and Paul Chodas of NASA's Jet Propulsion Laboratory believe that Lovejoy is the harbinger of greater sungrazing comets that may arrive in the next several years, so stay tuned.

C/1927 X1

Comet Skjellerup-Maristany (C/1927 X1) was the first scientists observed in infrared light. American astronomer Carl Lampland used a telescope at Lowell Observatory to catch its heat, though he failed to publish his data, which showed that forward scattering enhanced the brightness more than tenfold when the angle was 30° compared to when it was 90°. YERKES OBSERVATORY/NASA ASTROPHYSICS DATA SYSTEM

C/1910 A1

LOWELL OBSERVATORY

The **Great January Comet (C/1910 A1)** and comets **West (C/1975 V1)** and **McNaught (C/2006 P1)** were similar in their absolute magnitudes, small perihelion distances, and small scattering angles, allowing them to become visible to the naked eye in broad daylight. The Great January Comet and West were best visible from the Northern Hemisphere, while McNaught shone in the south. All three had stunning, broad, striated dust tails.

C/1882 R1	C/1910 A1	1P (1910)	C/1927 X1	C/1948 V1	C/1965 S1	C/1969 Y1	C/1975 V1	C/1995 O1	C/1996 B2	C/2006 P1
2 (135)	0 (20)	1 (80)	0 (32)	1 (47)	0 (30)	1 (80)	1 (55)	2 (215)	1 (72)	1 (42)
6 (0.8)	1 (5.0)	3 (3.4)	1 (5.5)	1 (5.1)	0(6.4)	3 (3.6)	2 (4.0)	8 (−1.1)	1 (5.4)	3 (3.9)
11 (0.016)	8 (0.141)	1 (0.854)	6 (0.211)	4 (0.340)	11 (0.030)	3 (0.538)	6 (0.219)	1 (0.914)	1 (0.985)	7 (0.181)
1 (0.989)	1 (0.859)	5 (0.158)	1 (0.774)	1 (0.680)	1 (0.969)	1 (0.736)	1 (0.800)	0 (1.351)	5 (0.135)	1 (0.824)
5 (16)	3 (30)	3 (35)	7 (78)	3 (29)	3 (29)	1 (78)	3 (32)	0 (>90)	1 (69)	3 (31)
25	13	13	15	10	15	9	13	11	9	15

1P (1910)

Halley's Comet was more impressive when it returned in 1910 than it was in 1835, owing to its close approach to Earth and its low scattering angle. The dust tail, brightened by forward scattering, stretched across the morning sky before it transited the Sun. Just before this crossing, several people in Australia saw the comet in daylight at an extreme scattering angle of 1°. Halley's 1985–86 apparition, however, was poor and didn't make the cut. But there's hope for those who can hang on: When Halley appears in 2061, it will be an indisputable Great Comet. Near its perihelion passage, its forward-scattering-enhanced magnitude should be near –1.8, brighter than the brightest star in the sky, and its total score should be 11 points. NASA ASTROPHYSICS DATA SYSTEM/ROYAL ASTRONOMICAL SOCIETY

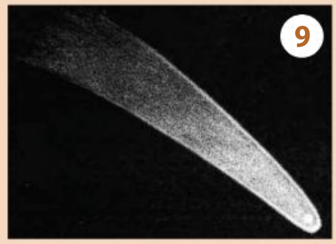
C/1874 H1

Comet Coggia (C/1874 H1) appeared in July 1874 and benefited from a forward-scattering boost. MAIK MEYER

C/1948 V1

C/1948 V1 was discovered during the totality of a solar eclipse and had a tail some 30° long. CHARLES F. CAPEN'S SKETCH FROM DAVID J. EICHER LIBRARY

C/1811 F1



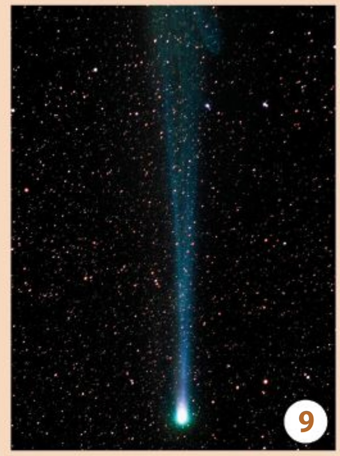
Because the **Great Comet of 1811 (C/1811 F1)** and **Comet Hale-Bopp (C/1995 O1)** had significant nuclei and large perihelion distances, they hung around for a long time, making strong impressions on the public. AMEDEE GUILLEMIN

C/1858 L1

BILDERATLAS DER STERNENWELT

Comet Donati (C/1858 L1) was a gorgeous comet that made a strong impression in the Northern Hemisphere in October 1858 when moderate forward scattering brightened its dust tail. The **Great Southern Comet (C/1865 B1)**, on the other hand, appeared in the Southern Hemisphere and had a nearly 90° scattering angle.

C/1996 B2



ROD POMMIER

When **Comet Hyakutake (C/1996 B2)** made its close approach to Earth in late March 1996, its tail spanned dozens of degrees. Both Hyakutake and **Comet Bennett (C/1969 Y1)** make the Great Comets list even though they had large scattering angles. Bennett appeared in the northern morning sky, while observers 150 years earlier saw **Comet Tralles (C/1819 N1)** after sunset for several weeks in July of 1819, when it had a tail some 14° long.

Comet designation indicates year of discovery (apparition for periodic comets); images are shown in order of "scorecard" ranking.

NASA/ESA/HUBBLE HERITAGE TEAM (STScI/AURA)

How great will Comet ISON be?

Based on what astronomers know right now, Comet ISON will come within 680,000 miles (1.1 million km) of the Sun but will not come closer than 37 million miles (60 million km) to Earth. Forward scattering will enhance our view, though not by much. ISON may or may not break the nine-point barrier to become a Great Comet; we will have to watch and wait. Its absolute magnitude and naked-eye visibility, both of which depend on the composition of its nucleus, will remain up in the air, so to speak, until the comet actually appears. If its nucleus is small, its close passage to the Sun might destroy it. That would be a showstopper. But let's take heart from Yogi Berra, who famously said, "It ain't over 'til it's over."

A+ TO LEARN HOW TO SCORE OTHER NOTABLE COMETS, VISIT **www.Astronomy.com/toc.**

COMET OF THE CENTURY?

Comet ISON brightens before dawn

This celestial visitor approaches naked-eye visibility as it slices through the background stars of Leo the Lion. **by Richard Talcott**

Comet ISON glowed around 16th magnitude and displayed a short tail when the Gemini North Telescope captured it May 4. GEMINI OBSERVATORY/AURA

The Sun's rays fall warmly on the icy surface of Comet ISON (C/2012 S1) during October. By the end of the month, the comet will lie as close to the Sun as Earth does. Like a summer's day in Greenland or Antarctica, the incoming radiation will heat ISON's ices. Unlike on Earth, however, the ices won't simply melt. Instead, solar energy will cause them to turn directly into gas, or sublimate. As the gas erupts from the surface, it carries dust with it.

ISON should release a lot of gas and dust, which will form a nearly spherical head, or "coma," around the comet's nucleus. Sunlight will reflect off the dust particles, creating a bright yellowish glow, and energize the gas molecules so they emit light tinted slightly blue.

Exactly how much material spews from the comet will determine how bright it will appear. Some experts think it could rival the brightest comets of the past century when it plunges close to the Sun in late November. They base these estimates off the comet's surprising brightness when astronomers working for the International Scientific Optical Network — ISON for short — discovered it beyond the orbit of Jupiter on September 21, 2012. (The designation C/2012 S1 indicates that the comet was the first to be discovered during the second half of September 2012.)

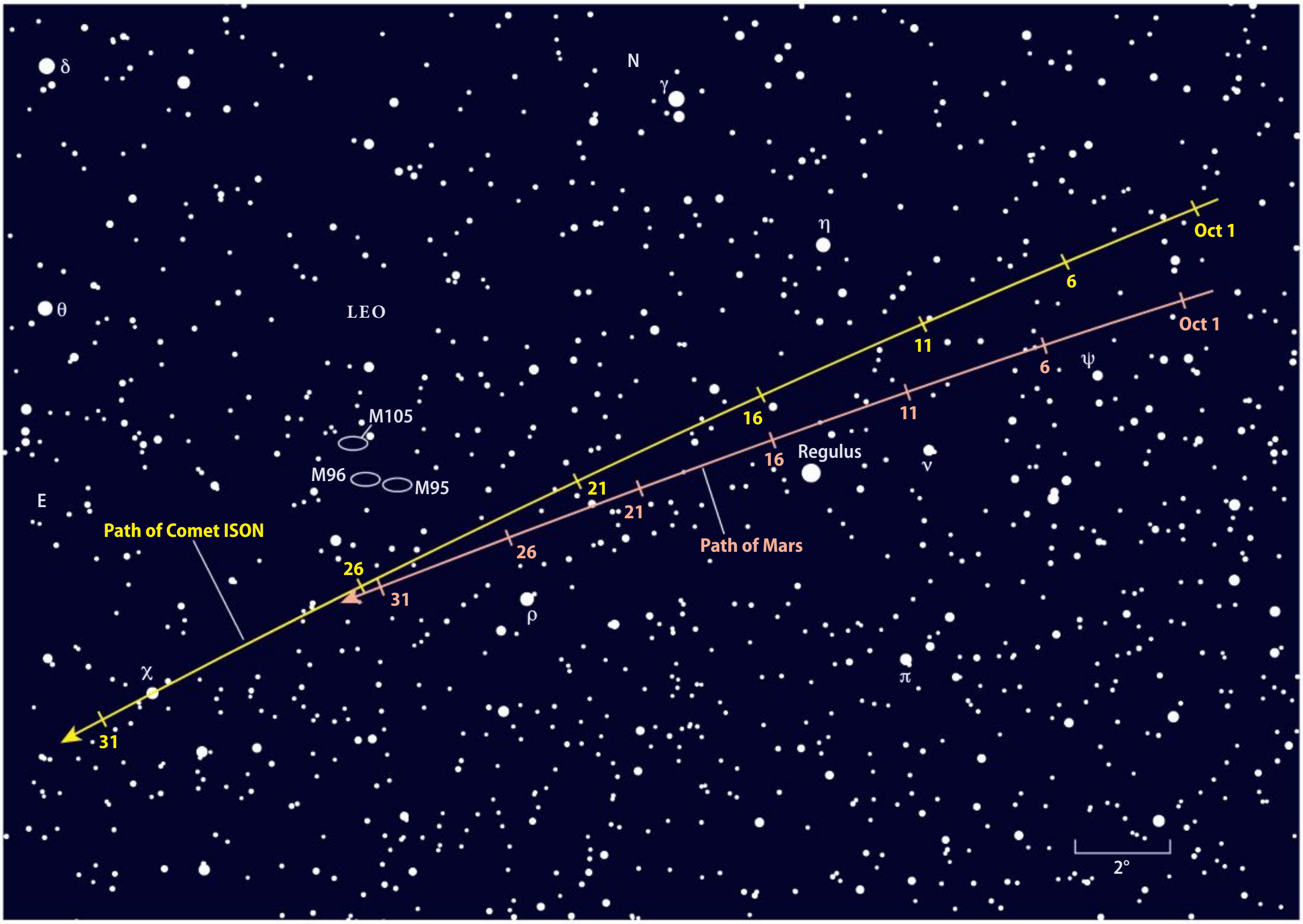
Other researchers predict a more muted appearance. These estimates grow out of a suspicion that the comet's surface was littered with fresh ices that sublimate at relatively low temperatures, goosing the early brightness beyond what its current state can sustain. Even most pessimists, however, expect the comet to look spectacular through binoculars and impressive with naked eyes from under a dark sky.

Although the truth won't come out until the waning days of November, October offers an enticing sneak peek. First, ISON should grow significantly brighter during the month. Astronomers expect it to glow around 9th or 10th magnitude in early October, bringing it within range of 4- to 6-inch telescopes under good conditions. By late in the month, ISON should be at least 10 times brighter and knocking on the door of naked-eye visibility at 6th or 7th magnitude.

Second, the comet is at its highest in the predawn darkness this month. From

MOON PHASES IN OCTOBER

New Moon	Oct. 4
First Quarter	Oct. 11
Full Moon	Oct. 18
Last Quarter	Oct. 26



Comet ISON crosses Leo this month, following a similar track to Mars but moving slightly faster. The map shows stars as faint as magnitude 8.7. *ASTRONOMY*: ROEN KELLY

mid-northern latitudes, it stands more than 30° above the eastern horizon as twilight starts to paint the sky. Finally, the comet leaves behind the relatively dim stars of Cancer the Crab for the richer stellar bounty found in Leo the Lion. The Lion's luminaries provide handy signposts for tracking ISON.

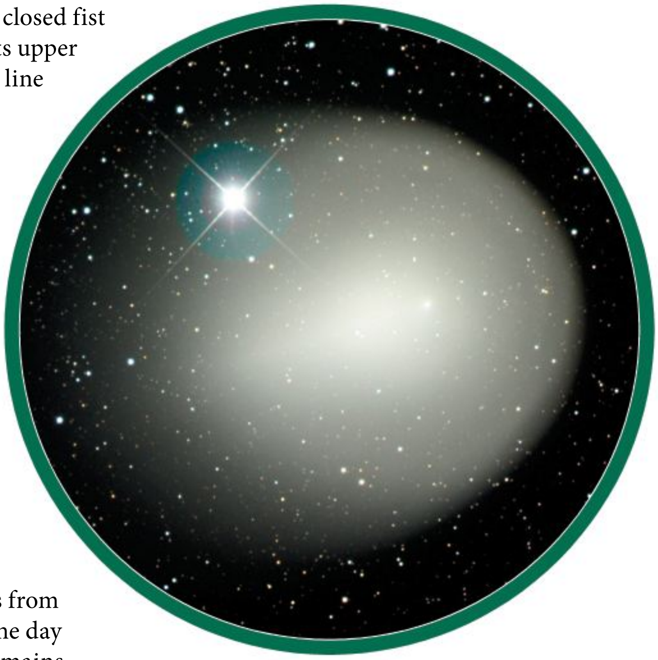
A martian encounter

But your best guide to finding the comet in early October is Mars. The Red Planet begins the month just 2° (four times the Full Moon's diameter) south of ISON, a gap that drops to 1° by the 15th. Not only is Mars bright, shining at magnitude 1.6, but it also has a distinctive orange-red color that makes it easy to find on any clear morning. Once you center the planet in a low-power field of view, gently nudge your scope northward to locate ISON.

A slender crescent Moon can aid your search on the 1st. It hangs fairly low in the eastern sky before dawn with Mars some 8° — the approximate width of a closed fist when held at arm's length — to its upper left. ISON stands along the same line about 2° beyond the planet. The 6th-magnitude star 8 Leonis lies roughly halfway between Mars and the comet.

The appearance of ISON near Mars is not simply a line-of-sight coincidence — the two bodies actually reside near each other in space. They make their closest approach October 7, when the comet whizzes 6.7 million miles (10.8 million kilometers) from the planet. If viewed from Mars that day, ISON would glow around 2nd magnitude.

The waning Moon disappears from the morning sky by October 3, one day before it reaches New phase. It remains out of the predawn sky until a day or two before Full Moon arrives on the 18th.



Comet 17P/Holmes passed near 2nd-magnitude Mirfak in November 2007. ISON will slide 2° north of 1st-magnitude Regulus in mid-October. BRIAN KIMBALL

CATCH AUTUMN'S OTHER PREDAWN COMET

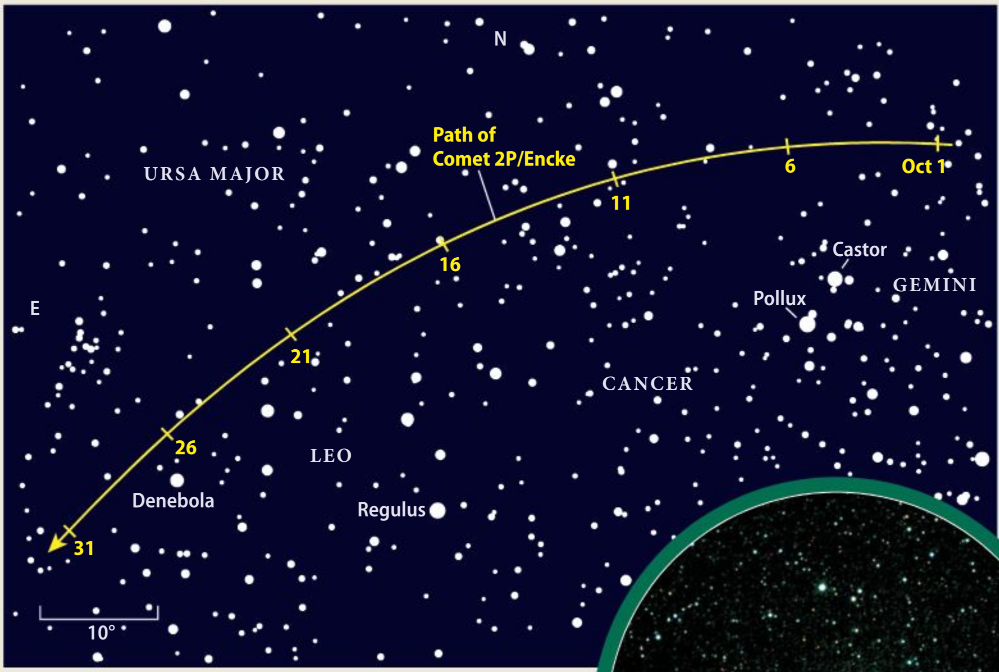
Although Comet ISON seemingly gets all the attention, it's not the only comet on display these October mornings. This month's second fiddle goes by the name 2P/Encke — and it was the second comet scientists recognized as being periodic. German astronomer Johann Encke calculated its orbit in the late 1810s, more than a century after Edmond Halley gained fame for predicting the return of his namesake comet.

But Comet 2P/Encke has an observational history that rivals that of its better-known cousin, 1P/Halley. French observer Pierre Méchain, a contemporary of comet-hunter Charles Messier, first sighted the comet January 7, 1786. With only one other observation to go on, however, astronomers were unable to calculate an orbit. The comet returned in 1795, 1805, and 1818, yet no one could make sense of its motion. The problem: Everyone thought the different appearances were unique comets making their first foray into the inner solar system.

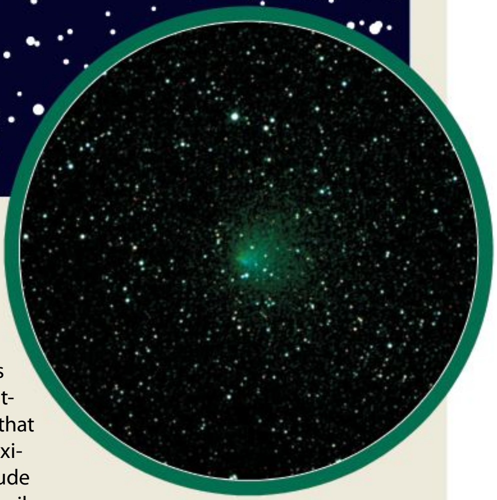
When Encke analyzed the 1818 observations, however, he realized it was a periodic comet with a 3.3-year orbit and managed to tie it to the previous apparitions. When the comet returned in 1822 as he predicted, it officially became Comet Encke.

Although this comet returns to Earth's sky every 3.3 years, the geometry of the Sun, Earth, and the comet nearly repeats after three orbits, or approximately 10 years. This makes the 2013 return its best morning appearance in a decade. It rides high in the eastern sky before dawn, above ISON during most of October. It moves quickly, however, beginning the month north of Gemini and ending it in Virgo. The finder chart above will get you to the right spot.

Because Comet Encke is periodic, it behaves predictably. Astronomers expect that it will brighten from approximately 11th to 7th magnitude during October, roughly similar to ISON. For the best views, use binoculars or a telescope and observe under a dark sky. — *R. T.*



Comet 2P/Encke races across the predawn sky to the north of ISON during October. Encke moves faster than its neighbor because it lies closer to Earth. *ASTRONOMY*: ROEN KELLY



Comet 2P/Encke last lit up the morning sky a decade ago. Look for a repeat performance this autumn. MIKE HOLLOWAY

From that date on, ISON viewing becomes more difficult because scattered light from the bright Moon reduces contrast between the sky and celestial objects. Fortunately, the brightening comet should help compensate for the lower contrast.

And Regulus makes three

Keep a watch on the morning sky during October's first two weeks, and you can't help but notice that Mars and its cometary companion are approaching a conspicuous star. This is magnitude 1.4 Regulus, Leo's brightest sun and a near match to Mars in terms of brightness. The star's subtle bluish hue, however, contrasts nicely with the ruddy planet.

The seemingly lockstep motions of Mars and ISON carry them to within a stone's throw of Regulus on October 15. The three objects form a spectacular straight line that morning, with Mars 1° north of Regulus and ISON 1° north of the planet. The trio rises shortly before 3 A.M. local daylight time and climbs one-third of the way to the zenith by the time morning twilight starts around 5:30 A.M.

This would be a great morning to capture photos of the celestial lineup. Your best shots will come through a telephoto lens that provides a 5° to 10° field of view. Experiment with different ISO settings and exposure times. The experience you gain now will help you hone your technique for the peak of ISON's show in November and December.

October 15 also would be a good time to examine ISON's tail. A comet typically produces two tails — one made of ionized gas and the other of tiny dust particles — though one often dominates the other. The gas tail forms from the molecules created when the comet's ices sublimate. Ultraviolet radiation in sunlight strips one or more electrons from these molecules (ionizes them), and the magnetic fields sculpted by the solar wind blow them directly away from the Sun.

The dust particles liberated from the comet's nucleus create the other tail. Solar radiation exerts pressure that gently pushes these particles away from the Sun, and they eventually spread out along the comet's path. With the Sun below the eastern horizon before dawn and the comet above it, it should come as no surprise that the tails point nearly straight up.

Both the gas and dust tails will grow longer and brighter as the comet rounds

Richard Talcott *is an* Astronomy *senior editor and author of* Teach Yourself Visually Astronomy *(Wiley Publishing, 2008).*

Comet McNaught (C/2009 R1, below center) zipped past the edge-on spiral galaxy NGC 891 (above center) in Andromeda during June 2010. ISON will encounter three similarly bright galaxies — M95, M96, and M105 — in Leo during late October. JOHN CHUMACK

the Sun in late November and re-emerges into a dark sky in December, but they should start showing up through amateur equipment in October. With the Moon set to return to the morning sky shortly after October 15, however, you likely won't see them better until November.

A Messier meeting

By October's second half, Comet ISON's impending rendezvous with the Sun manifests itself in the sky. As the visitor from the solar system's depths feels the relentless pull of our star's gravity, it starts to pick up speed and soon leaves Mars behind. Their 1° separation on the 15th grows to 7° by the 31st. Still, the two share a surprising link — the comet's tail points directly toward the planet during October's final days.

With ISON's quicker motion against the rich backdrop of Leo, attractive encounters become more common. From the 22nd to the 24th, the comet appears no more than 2° from 4th-magnitude Rho (ρ) Leonis. The two form an equilateral triangle with Mars on the 24th.

But the finest late-October meeting has to be ISON's passage just south of a trio of bright galaxies: M95, M96, and M105. On the morning of October 25, the comet passes a bit less than 2° south of 10th-magnitude M95 and 9th-magnitude M96. (Ninth-magnitude M105 lies nearly 1° farther to the north-northeast.)

The galaxies should provide a touchstone for comet observers. A comet's light spreads out over a measurable sky area, just like a galaxy's does. So, it's far easier to compare the brightness of a fuzzy comet to an extended galaxy than to compare either with a pointlike star. Astronomers predict that ISON should glow around 7th magnitude on the 25th, which would make it noticeably brighter than any of these background galaxies.

A lunar reprise

The waning crescent Moon returns to ISON's vicinity as October winds down. It passes 6° south (to the lower right) of the comet on the 30th, when it appears 18 percent lit. Look for the ashen light of earthshine on the 82 percent of its surface not in direct sunlight. The lunar crescent appears noticeably thicker on the 30th than it did on its previous comet visit October 1.

Although the Moon likely will draw your attention on the 30th, don't overlook the comet's close encounter with the 5th-magnitude star Chi (χ) Leonis that same day. The comet's nucleus passes within 2' of the star, and the coma's gas and dust should dim the star's light.

As October gives way to November, the Moon exits the morning sky and leaves the stage for ISON's command performance. The comet will dive through Virgo and Libra, skipping past 1st-magnitude Spica at midmonth before making a hairpin turn around the Sun on November 28. It skims within 1.2 million miles (1.9 million km) of our star's center on that date and should shine brightest. We'll be back next month with all you need to know about the show.

FOR CONTINUING UPDATES OF ISON'S PROGRESS, VISIT **www.Astronomy.com/ISON.**

ORDER from CHAOS: Genesis samples the solar wind

This NASA spacecraft captured and returned atoms from the Sun to Earth. What happened next took "recovery" to a whole new level. **by Meenakshi Wadhwa**

Our Sun contains more than 99 percent of the mass of the entire solar system, so its chemical makeup is a close match for the original disk of gas and dust (the solar nebula) from which it and the planets formed approximately 4.6 billion years ago. Therefore, if we really want to understand our origins and answer questions about why and how the planets formed and evolved the way they did, we need to understand the chemistry of the Sun. But just how do you grab a sample of our star to measure its chemistry?

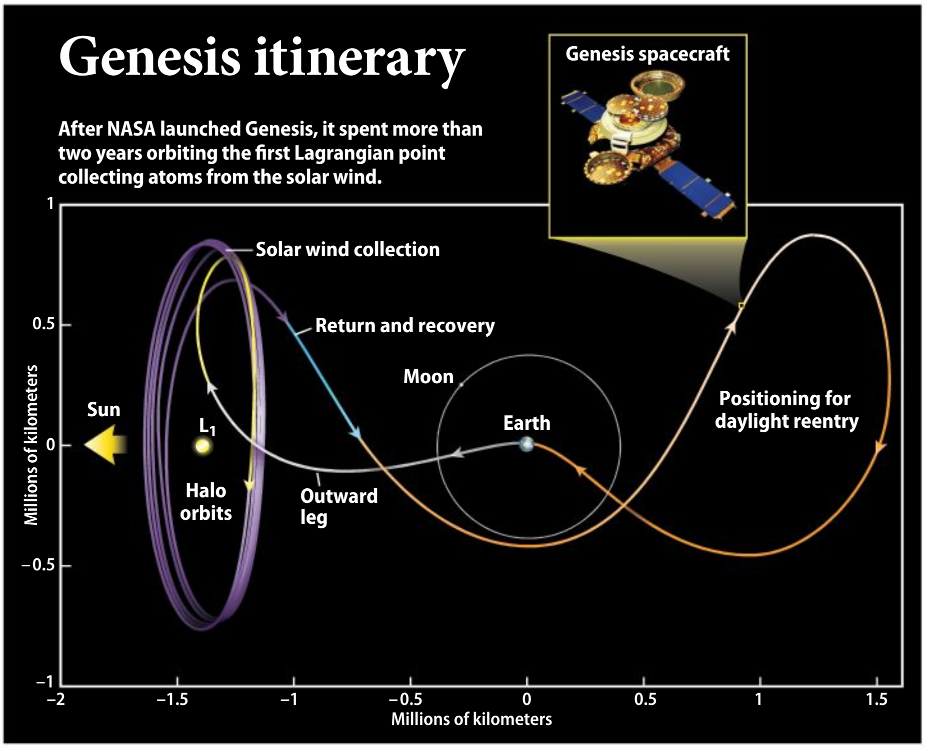
Actually, the Sun is ejecting atoms constantly from its outer layers in a dilute, highly ionized stream called the solar wind that flows radially outward at a speed of about 1 million mph (1.6 million km/h). If researchers could capture and return to Earth enough solar wind atoms, they would indeed have a sample of the Sun to measure in state-of-the-art laboratories here on Earth. That was the fundamental idea behind the Genesis mission, which was NASA's first sample-return mission since the agency's last Apollo mission, when astronauts aboard Apollo 17 brought back material from the Moon in 1972.

Catching a piece of the Sun

Genesis, a NASA Discovery-class mission, was launched August 8, 2001. Former NASA Administrator Dan Goldin described this class of mission as a "faster, better, cheaper" means of realizing our country's scientific and exploration goals. To maximize the quality and amount of the solar wind sample the spacecraft would return, scientists programmed it to orbit the first Earth-Sun Lagrangian point, also called L1, for about 27 months. Lagrangian points are five positions near Earth and the Sun where a small mass (like a spacecraft) can remain in a fixed position with respect to the two larger bodies.

During this time, the solar wind fell onto a variety of high-purity materials that served as "collectors." The first type were 4-inch (10 centimeters) hexagons mounted in five circular arrays. The solar wind interacted with these for different periods during the mission. The second type was a set of four quadrants with radii of 1.2 inches (3cm) mounted in the center of an ion-focusing device called a "concentrator" that collected a focused sample of solar wind.

As is true for every spacecraft mission, tremendous effort went into the planning prior to launch. Genesis, though, had an additional challenge: Despite the exposure of the collectors to the solar wind during many months, the atoms astronomers hoped to capture would constitute an exceedingly tiny amount of sample. At the L1 distance — more than 92 million miles (148 million kilometers) from the Sun on average — there are typically less than 10 atoms in a volume of one cubic centimeter, and most of them are hydrogen.



ASTRONOMY: ROEN KELLY, AFTER NASA/JPL

Meenakshi Wadhwa *is director of the Center for Meteorite Studies at Arizona State University in Tempe. She wrote this article while appointed as Visiting Scientist at the Lunar and Planetary Institute in Houston.*

The Genesis spacecraft carried several special materials within collecting trays. Engineers carefully crafted the detectors so they were free of impurities.

For researchers to make precise and accurate analyses of such a small amount of sample, the collector materials had to be manufactured free of earthly contaminants and, moreover, had to be carefully handled thereafter. So the mission team manufactured all of the detectors to high-purity specifications and then installed them in trays and holders inside a clean room specially constructed for this purpose.

A tough job made tougher

In the case of every sample return mission, the science really begins when the material arrives on Earth. The Genesis Sample Return Capsule (SRC) containing the collected solar wind returned September 8, 2004. According to the principal investigator, Donald Burnett, the project literally hit bottom that day.

The parachute on the SRC failed to deploy, causing it to crash into Utah's Dugway Proving Ground. The mission team was left to pick up the pieces. But as Burnett wisely said, if a spacecraft has to crash, the best place to crash it is Earth! That way, researchers might salvage some material, and there is the added advantage of virtually limitless time and technologies available in Earth-based laboratories to extract valuable information from the material.

Following the crash, scientists began the painstaking task of recovering as many fragments as possible of the previously pristine collector materials that shattered into thousands of pieces now coated in Utah dirt. The team transferred these fragments to the Astromaterials Acquisition and Curation Office at NASA's Johnson Space Center in Houston.

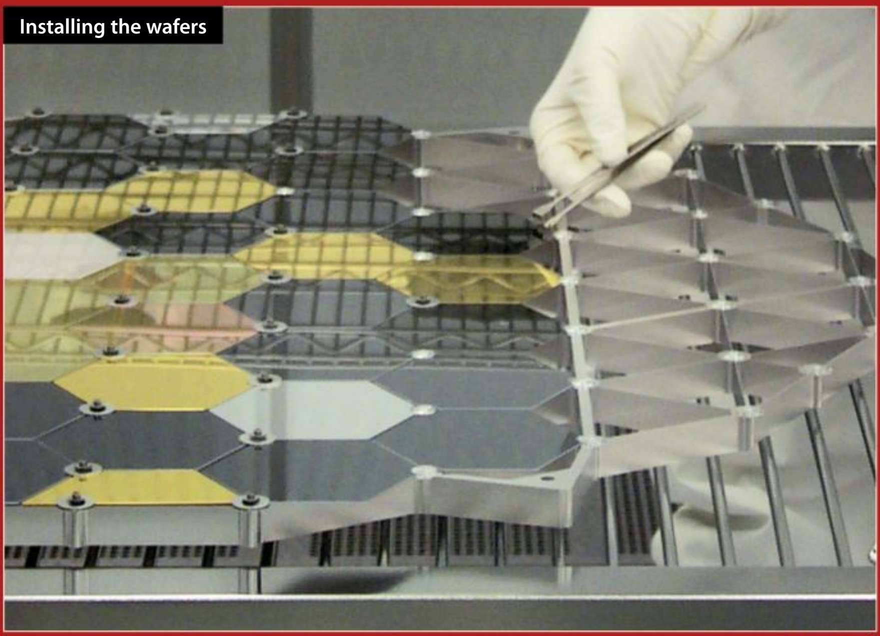
This sample-curation facility has since proved critical to extracting valuable

NASA launched the Genesis mission August 8, 2001. It was the first spacecraft to return material from beyond the Moon's orbit. ALL PHOTOS: NASA

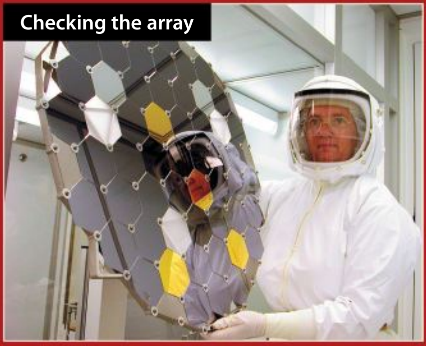
GENESIS BEFORE LAUNCH

NASA technicians readying the spacecraft had to work in a specially constructed clean room to ensure that the sample collectors picked up no earthly contaminants. Such an environment employs air filtration that removes bacteria, dust, and other airborne pollutants. Workers, who enter and leave via air locks, wear hoods, face masks, gloves, boots, and coveralls.

Installing the wafers

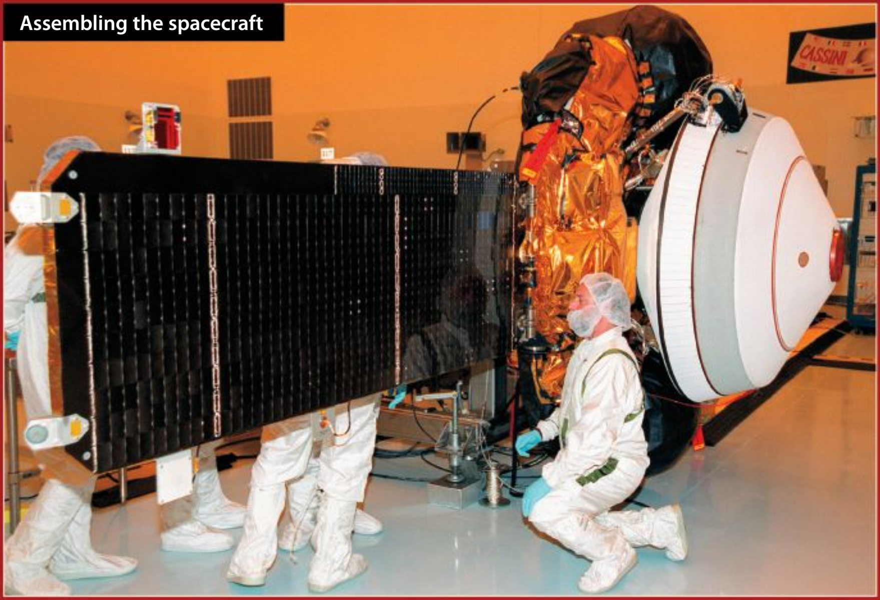


Checking the array



Inspecting the collectors

Assembling the spacecraft



scientific information from these fragments. A highly skilled team worked closely with Genesis science team members to develop innovative methods for careful and thorough cleaning, documentation, and subdivision of the Genesis sample collector fragments so scientists in laboratories around the world could study them.

One of the many amazing facts about the Genesis mission is that at the time NASA launched the spacecraft, the instrumentation required to achieve the highest-priority scientific objectives did not even exist. Mission scientists constructed each of the instruments for the purpose of analyzing the solar wind sample.

One such instrument is the Secondary Ion/Accelerator Mass Spectrometer (MegaSIMS) at the University of California, Los Angeles. This behemoth occupies an entire room and weighs more than the Genesis spacecraft (which tipped the scales at 1,090 pounds [494 kilograms])! It speaks to the vision and creativity of the international scientific community that, despite all of these challenges, the Genesis mission has been able to achieve its highest-priority goals.

The Sun is normal, but we are not

The highest science objectives of the Genesis mission were to precisely and accurately measure the isotope ratios of the elements oxygen, nitrogen, and the noble gases in the Sun. The isotopes of an element are different forms of those basic substances that have slightly different atomic masses because they contain different numbers of neutrons. Knowing those ratios will help researchers improve theories about the origins of the Sun and planets.

Less than a decade following the crash of the Genesis SRC into the Utah desert, the science team achieved those objectives. In so doing, they gave us important pieces to the puzzle that relates how the planets in our solar system were put together.

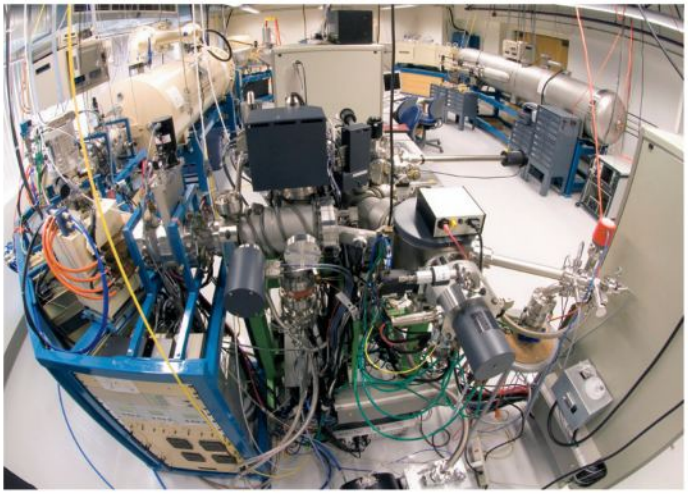
Next to hydrogen and helium, oxygen and nitrogen are among the most abundant elements in our solar system. Measuring their isotope ratios in the solar wind sample returned by the Genesis mission has given scientists their most precise estimates for the isotope abundances of these elements in the Sun. And when researchers compared the solar composition with that previously measured for Earth, they discovered that the Sun's composition is slightly, yet distinctly, different from that of our planet.

But because our star makes up more than 99 percent of the mass of the solar

Because a parachute failed to deploy and slow the Genesis sample return capsule's descent, it crashed into the desert floor of the Dugway Proving Ground in Utah at 193 mph (311 km/h). Luckily, the ground was muddy, so the damage was not as great as scientists feared.

A technician at the Johnson Space Center in Houston cleans a fragment of the sample collector to remove the dust that covered it after it impacted the Utah desert.

The recovery team eventually secured the sample return capsule and as many of its solar wind atom-collecting wafers as possible. The team then moved it to a clean room for analysis. They also surveyed the desert crash site so they could identify possible contaminants.



The Secondary Ion/Accelerator Mass Spectrometer (MegaSIMS) is an instrument engineers built and set up at the University of California, Los Angeles, to test samples returned by the Genesis mission. The MegaSIMS analyzed the isotopes of oxygen in the solar wind.

system, we can think of it as the initial ("normal") composition of the nebula from which the solar system formed. Earth seems to be made from a mix of materials different from the Sun.

Another interesting wrinkle is that the Sun's composition in terms of nitrogen isotopes matches that of the gas-giant planet Jupiter. This highlights the fact that while the most massive bodies in our solar system (such as our star and Jupiter) arose from the normal composition of the solar nebula, Earth and other bodies in the inner solar system (such as meteoroids and asteroids) are made of slightly different stuff. Now the question is: How did this material come about? As with any successful mission, Genesis answered some questions, but it also raised new ones.

Lessons learned

One of the biggest lessons from the Genesis mission is that, given enough time and enough innovative people working together, it is possible to recover from even dire situations. Despite the Genesis spacecraft's "off-nominal" landing, its team has accomplished the highest-priority scientific objectives of the mission, well within a decade of first recovering the sample. And, in fact, researchers think there are no Genesis mission science objectives that are unachievable — they will complete them all with more time and ingenuity.

Therein lies the great advantage to bringing samples from other places in our solar system back to Earth: Even if present state-of-the-art instrumentation is unable to make the measurements required to address certain key questions, with careful curation the returned samples can be available for future investigations. Then, with greatly advanced methods and technologies, we will assuredly be able to answer those questions.

10 great autumn binocular sights

Before the chill of winter sets in, head outside to explore a variable star, a nearby galaxy, a stellar waterfall, and more. **by Phil Harrington**

The Milky Way's disk holds a greater than average number of binocular objects. The galaxy's glittering band is high in the sky during autumn, so this season is a wonderful time to tour the universe through binoculars. What's in the sky to view with yours tonight? Head outside to hunt these 10 terrific targets.

Let's kick things off in Capricornus. In the northwestern corner of this triangular constellation await the pretty double stars **Alpha (α) and Beta (β) Capricorni**, which fit into the same binocular field. Even the tiniest pocket binoculars can resolve the two 4th-magnitude stars that compose Alpha Capricorni, properly named Algedi. They are not a true physical pairing, however. Instead, the stars only appear aligned as seen from Earth. The western sun, Alpha^1, is 690 light-years from us while Alpha^2 is just 109 light-years away.

The two suns of Dabih (Beta Capricorni), on the other hand, form a true binary system. The brighter, dubbed Dabih Major, shines with an orange color at magnitude 3.1 while its companion, Dabih Minor, is only magnitude 6.1 and looks slightly bluish. Both are 330 light-years away, and about ⅓ light-year separates them.

Next, head north to Cygnus and brilliant Deneb (Alpha Cygni), a radiant beauty through binoculars. Scan 9°, or a bit more than one binocular field, to Deneb's northeast along the Milky Way, and you will arrive at open cluster **M39**. Look for a tiny triangular grouping of about two dozen faint points. Viewed from a dark location, M39 appears almost three-dimensional, as if suspended in front of a blanket of faint stardust.

Our next target stood out to German-born English astronomer William Herschel. He nicknamed **Mu (μ) Cephei** the "Garnet Star" because of its striking orange-red color. Mu is one of the largest and brightest red supergiants in the Milky Way, with a diameter spanning farther out than Saturn's orbit. View the Garnet Star and pure-white Alderamin (Alpha Cephei) in the same field to enhance the ruby color. Like most red supergiants, Mu also pulsates: Over a semi-regular period of about 850 days, it cycles between magnitude 3.4 and 5.1.

Mu (μ) Cephei is a variable star that changes its brightness by nearly five times over the course of about 2.5 years. Members of the American Association of Variable Star Observers monitor this red supergiant. ANTHONY AYIOMAMITIS

Heading back to observing star clusters, extend a line from Schedar (Alpha Cassiopeiae) to Caph (Beta Cassiopeiae), the westernmost stars in Cassiopeia's W asterism, and continue an equal distance farther northwest to spot **M52**, one of my favorite autumn open clusters. There, you should spot a slender four-star diamond-shaped asterism, with M52 just to its south. Two hundred stars call this cluster home, but only a few are bright enough to crack the

Open cluster M52 lies less than 1° from the Bubble Nebula (NGC 7635) in Cassiopeia, but the nebula requires at least an 8-inch telescope to spot it. BERNHARD HUBL

Phil Harrington *is a contributing editor of* Astronomy *and author of* Cosmic Challenge *(Cambridge University Press, 2010).*

M39, an open star cluster in Cygnus the Swan, lies about 800 light-years away from Earth. Its stellar members are a youthful 300 million years old. ANTHONY AYIOMAMITIS

binocular barrier. The rest blend into a cloud of misty starlight.

NGC 663 is another stellar conglomeration. This one lies a little to the east of the halfway point between Ruchbah (Delta [δ] Cas) and Segin (Epsilon [ε] Cas) along the eastern arm of Cassiopeia's W. Through my 10x50 binoculars, this open cluster looks like an unresolved blur of light. By switching to my 16x70s, I can just begin to pick out a few feeble points within. Open cluster M103 lies just 2° to the southwest, but most observers agree that NGC 663 puts on a much better show.

STEVE COE

Kemble's Cascade is an asterism that spans about five Full Moons in Camelopardalis the Giraffe. At the base of the "waterfall" is the cluster NGC 1502.

Next, scan about one-third of the way from Segin toward Polaris (Alpha Ursae Minoris). Pause when you spot the Keystone asterism formed by 40, 42, 48, and 50 Cassiopeiae, and then look carefully inside. Can you see a dim smudge? If so, you've spotted **Collinder 463**, a little-known collection of about eighty 8th-magnitude and fainter suns. Take a careful look. Does the cluster appear crescent-shaped to you, as some report?

For another variable star, head to **Algol** (Beta Persei), the famous "Demon Star" in Perseus that is fun to follow through binoculars. Every 2 days, 20 hours, and 49 minutes, Algol "blinks" at us as it drops from magnitude 2.1 to 3.4. These changes result from a much dimmer companion star passing in front of the binary system's primary sun. Each eclipse lasts about 10 hours. Time it for yourself to see the universe in action.

A few years ago, I included the Andromeda Galaxy (M31) as an autumn binocular target. This year, we shift 15° southeast to the **Pinwheel Galaxy** (M33), another member of the Milky Way's Local Group of galaxies. But while M31 was easy to spot, M33 may give you a run for your money. Look for the galaxy's faint glow about halfway between the stars Mirach (Beta Andromedae) and Mothallah (Alpha Trianguli). Can't make it out? Try bracing your binoculars against a solid support and using averted vision.

Our final target sits in Camelopardalis. While scanning the seemingly barren constellation with his 7x35 binoculars more than three decades ago, the late Canadian amateur astronomer Lucian Kemble stumbled upon, as he described it, "a beautiful cascade of faint stars tumbling from the northwest down to the open cluster NGC 1502." **Kemble's Cascade**, as this asterism is now known, spans 2.5°. A lone magnitude 5 sun at midspan highlights this curious chain of some sixteen stars between 7th and 9th magnitude. This stellar stream flows some 15° east of Segin. And once you spot Kemble's Cascade, be sure to look for NGC 1502 at its southern tip.

These are just some of the targets in autumn's binocular universe. If it's clear tonight, head outside to enjoy a bit of what the season has to offer. And as always, when it comes to stargazing, remember that two eyes are better than one.

DISCOVER MORE FALL BINOCULAR TARGETS AT **www.Astronomy.com/toc.**

Spice up your images with Hydrogen-alpha data

An LRGB image (top) of the Dumbbell Nebula (M27) in Vulpecula shows its familiar appearance. The same object, however, takes on a dramatic new look after the addition of Hα data. It displays more internal detail, jets and puffs of red nebulosity around its edges, and an outer shell of previously ejected red gas extending far beyond its familiar contours.

Make your images shine by adding light through this narrowband filter. **text and images by Rod Pommier**

Deep-sky astroimaging is more popular today than ever. Electronic detectors have revolutionized the field, and amateur astronomers now have the capability to produce images that rival those done by professional astronomers at the world's best observatories only a few years ago.

Photographers produce LRGB or RGB images by combining exposures taken through clear luminance (L), red (R), green (G), and blue (B) filters. The majority shoot only the most popular objects.

While some masters of the art of astroimaging can process their LRGB photos of familiar objects into stunning celestial vistas, the rest of us usually produce versions that fall short of inspiring an emotional response. How, therefore, can we make deep-sky images that will stand out and truly captivate the viewer?

One way is to add an additional layer of data captured through a Hydrogen-alpha (Hα) filter. Hα light is red light at a wavelength of 656.28 nanometers. Hydrogen atoms in nebulae emit it chiefly as a result of ionization by radiation from nearby hot stars, but shock-wave energy released when interstellar hydrogen clouds collide also can produce it. Many astronomy dealers sell Hα photographic filters in various sizes that are compatible with the gamut of CCD cameras and filter wheels. Most have a bandpass width of 6nm or 7nm, which classifies them as narrowband filters.

Rod Pommier *is a surgical oncologist and professor of surgery at Oregon Health & Science University in Portland and an avid astroimager.*

Seeing in a new light

Our Milky Way teems with nebulae glowing in Hα light. Many such regions appear dim with little detail when imaged through standard filters. But in Hα light, those areas reveal bright, swirling clouds of gas, delicate tendrils and filaments of nebulosity, glowing shock fronts where clouds collide, and dramatically silhouetted wisps and clouds of dark dust. It is difficult for the human eye to detect Hα light, but this radiation actually is one of the brightest wavelengths emitted throughout the entire sky, so including it in our images opens an entirely new universe of possibilities.

Many familiar deep-sky objects take on surprising new appearances in Hα light. The fragments of nebulosity in the central region of the Dumbbell Nebula (M27), which typically appear fuzzy and blunted in LRGB images, pop out with sharp clarity in Hα. Even more surprising, both M27 and the Ring Nebula (M57) reveal outer shells of ejected red gas extending far beyond their familiar contours. Even images of nearby galaxies benefit from the addition of Hα data. For example, Bode's Galaxy (M81) and M101 show hydrogen clouds known as HII regions, which contrast beautifully with their blue spiral arms.

Other objects are notoriously difficult to image in RGB. For example, the Crescent Nebula (NGC 6888), which owns up to its name by appearing as a slim arc in RGB images, takes on the appearance of a spherical burst of fireworks in Hα. Countless other regions of the Milky Way normally ignored by imagers become fascinating targets in Hα light, providing a virtually inexhaustible source of interesting new subjects.

Having superb equipment under dark skies certainly helps experienced imagers. Others, however, must make do with less than ideal equipment, aimed through heat waves rising from their neighbors' roofs beneath light-polluted skies. Hα imaging can help offset some of those disadvantages.

Hα filters pass only a narrow slice of the spectrum, so they block most light pollution. They even cut moonlight, making it possible to image during more nights of the

month. Because fewer photons pass through an Hα filter, however, it takes more time to create an image.

Collecting data

For Hα imaging, you will need to shoot through a minimum of RGB and Hα filters. You can include luminance data, but it isn't required. With many subjects, I find the Hα data serve so well that separate luminance exposures are superfluous.

Acquire the (L)RGB data as you would for any standard image in terms of the number and duration of sub-exposures. Acquiring the corresponding Hα data should then be a simple matter of turning the filter wheel to "Hα" and collecting the additional exposures (whatever number you choose to stack into your final Hα component). Remember, the Hα exposures need to be longer than the others. I typically make them two to three times as long as any of my RGB exposures.

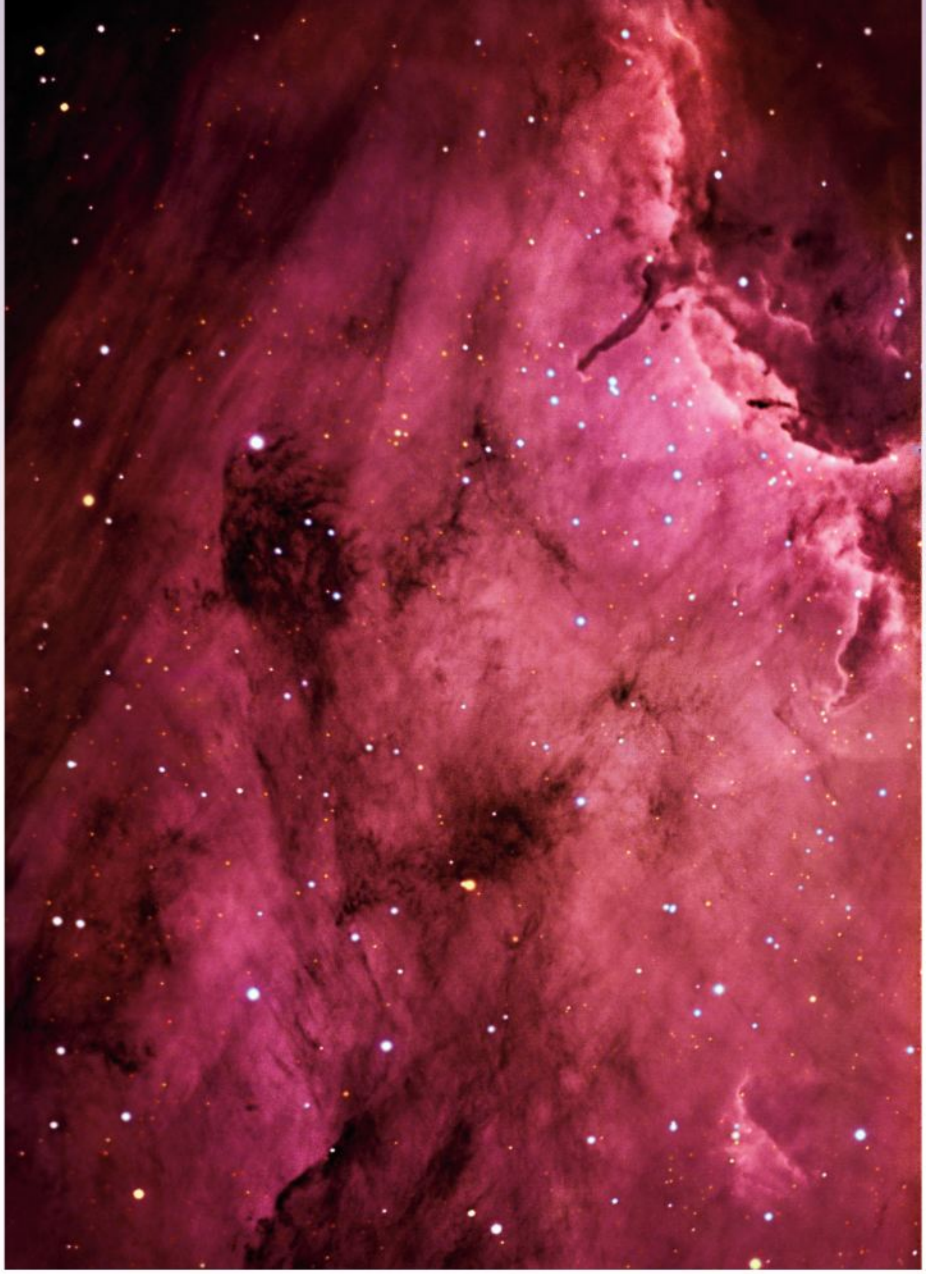
Autoguiding through an Hα filter also is more difficult. An Hα filter dims stars substantially. If you are using a self-guiding CCD camera with the guiding chip located behind the filter wheel, then guide stars bright enough through RGB filters may be too dim to use with the Hα filter.

Planetarium software that simultaneously shows the fields of view of the imaging and guiding chips superimposed on the sky can aid tremendously in finding the brightest possible guide star. If no suitable guide star is available, you may have to switch to a separate autoguider in either a piggyback guide scope or in an off-axis guider positioned in front of the filter wheel.

Image processing

After collecting your data, calibrate the RGB exposures and assemble them into a frame using image-processing software such as *Photoshop*. If you collected any luminosity data, do the same to make a master luminance frame. Then calibrate and assemble your Hα exposures into a master frame. Next, align the master frames so they overlap when you later stack them as layers in *Photoshop*. Alternatively, you can align them with that software's "Move" tool. Save all the aligned and resized master frames using appropriate file names.

Open the frames in *Photoshop*, and begin stretching the data using multiple iterations of "Curves" followed by resetting the black point after each curve. You may need to individually reset the black points for the RGB channels to keep the image color-balanced and free of color bias. Take care not to clip



This close-up hybrid HαRGB image of the Pelican Nebula (IC 5070) in Cygnus shows beautifully rich nebulosity silhouetting dramatic streamers, wisps, globules, and forking tendrils of dark dust. The region along the back of the Pelican's "neck," designated IC 6057 (upper right), shows a shock front where clouds of hydrogen are colliding with pillars and dark globules associated with star-forming regions. The long trunklike object Herbig-Haro 555 has threadlike projections extending from its tip because a newborn star forming within is ejecting material from its poles.

Despite more than 10 hours of combined LRGB exposures, the Crescent Nebula (NGC 6888, left) still appears as a dim arc of nebulosity with almost no internal structure. When the author added Hα data to the image, it transformed NGC 6888 into a much more extensive and beautiful nebula with rich internal structure.

How an image comes together

The four images on this page show the process the author uses to combine color and Hydrogen-alpha (Hα) data. These are the four master frames for his HαLRGB composite image of the "Mexico/Gulf of Mexico" region of the North America Nebula (NGC 7000). Stacking them in the "Layers" palette in *Photoshop* produced the final hybrid image (#5) shown on the next page. The stretched RGB frame (#1) is quite dim and shows little color. The stretched luminosity frame (#2) also is dim and shows little detail despite hours of exposure. Combining this with the RGB frame to the left would not make a captivating final LRGB image. The stretched Hα frame (#3) of the same region shows an amazing amount of otherwise hidden nebulosity and sharp detail. The red colorized version of the Hα frame (#4) produced in *Photoshop* provides the necessary color support in the final image.

any data, including the stars. Preserving star colors will provide contrast with the red Hα regions in the final image.

For some objects, the corresponding RGB images may still appear dark even after several iterations. Don't worry. As long as you can successfully stretch the image to the point where colors begin to show up, those colors will combine with the Hα image to produce a beautiful hybrid.

Assembling the hybrid image

The fun begins as you build an HαLRGB image with "Layers" in *Photoshop*. Make sure that palette is active, and open your RGB image. This will appear as the "Background" layer in the palette. If you have a processed master luminance frame, open it and copy and paste it on top of the RGB layer. If your luminance frame is still in grayscale mode, pasting it on top of an RGB image will automatically convert it to RGB color mode. Click on the icon for the luminance image in the "Layers" palette to highlight it and then change the "Blending Mode" at the top left to "Luminosity." You are now looking at either the LRGB or RGB image of your subject.

Next, open the Hα image. Copy and paste it on top of the stack. Because the default blending mode for any new layer you added to the stack is "Normal," all you will see at this point will be your Hα image. It will undoubtedly show considerably more nebulosity and detail than the underlying color image, but it will still appear black and white because you haven't applied any of the color from the underlying image.

Click on the icon for the Hα image in the "Layers" palette to highlight it, and change the "Blending Mode" to "Luminosity." This allows the colors from the underlying image to blend into the Hα image, but the result will be disappointing. While the hybrid image shows more extensive nebulosity, it will be washed out and almost colorless. At this point, the detail in the Hα image lacks color support from the underlying RGB image because those features don't even appear in the color image. You have to provide the necessary color support for the overlying Hα image, which, naturally, should be red.

To do this, produce a red colorized version of the Hα image to add to the stack. Click your Hα image in the central work area. On the top menu bar, click "Image," then "Duplicate." Then click "Image," "Adjustments," and "Hue/Saturation." In the window that appears, click "Colorize," and the image will suddenly take on color. To change the color, adjust the "Hue" slider. Pure red has a value of zero. Next, set the "Lightness" slider to –50 and click "OK." You now have a deep-red version of your Hα image. It will look the same as the black and white image viewed through red glasses. Rename the image "Hα_red," and save it.

This hybrid image of part of the North America Nebula (NGC 7000) resulted from a stack of images #1 through #4 at left. The author used *Photoshop*'s "Lighten" blending mode, as described in the text. The composite image combines the best features of the LRGB data and the Hα data into a single beautiful image. The final result reveals much more color saturation and intricate detail than either the LRGB or Hα images alone.

Copy the Hα_red image, and paste it on top of the black and white Hα image in the central work area. In the "Layers" palette, a new icon for the Hα_red image will appear at the top of the stack. Click its icon to highlight it, hold the mouse button down, and then drag the icon for that layer below the Hα layer and release the button. This will swap the order of the top two layers, putting the Hα_red layer beneath the Hα layer. Click the Hα layer icon to highlight it, then change the blending mode to "Luminosity." This will put the red color support into the Hα image.

The Elephant Trunk Nebula (IC 1396) is an emission nebula in the constellation Cepheus the King that contains a vast amount of dust. Adding Hα data to the standard color version of this image not only enhances the color but also increases the contrast between the bright and dark nebulosity.

Now we have red color support for the Hα data, but the image still won't be beautiful. That's because the red at the top of the stack is overwhelming the RGB data that lies beneath. Left-click the icon for the Hα_red image in the "Layers" palette to highlight it. Change the "Blending Mode" to "Lighten." What happened?

With the "Lighten" blending mode, *Photoshop* compares the data for each pixel in the top layer to the corresponding pixel in the layer beneath and then selects the brighter of the two. The final image isn't the monotone red colorized Hα image you produced, nor is it the dim background RGB image. Rather, it is the best of both: all the extra red nebulosity and detail seen in the Hα image, beautifully enhanced by the other colors in the RGB image.

Now fine-tune the result. Click on the "Opacity" slider at the top right of the "Layers" palette. By moving it, you control how much of the final image comes from the Hα data and how much from the RGB data. An opacity setting for the Hα layer somewhere around 50 percent usually gives a great look, but adjust it to your taste.

The end result will be a fantastic image sure to captivate you and your friends. Oh, and save a copy of your work as a *Photoshop* file with a PSD extension. That will include all the layers in your stack should you ever want to come back and adjust any of them. When you're satisfied, "flatten" the image.

Adding Hα data requires some extra imaging and processing time, but the results are well worth it. This technique will enhance your deep-sky images and make them truly beautiful.

Astronomy tests Denkmeier's Binotron-27

High-quality optics and superb mechanics make this accessory a winner. **by Mike Reynolds**

A number of excellent accessories exist for today's visual observer, ranging from cameras to filters to incredible eyepieces. One of my personal favorites — and always a crowd-pleaser when I am doing outreach — is my binoviewer, and we'll take a close look at a good one in this review. Simply stated, a binoviewer turns your single-eyepiece telescope into a binocular-like setup, allowing you to use both eyes.

One of the major reasons for using binoculars is human physiology: We have two eyes. In fact, the word *binoculars* comes from the Latin words *bini*, meaning double, and *oculus*, which means eye. And using both eyes has real advantages.

First, more light reaches the brain. Some researchers have measured a 40 percent increase. Second, resolution — the ability to distinguish between two close objects — increases. Third, image contrast — the ability to see and differentiate fine details — also increases. Fourth, many observers report an enhanced ability to detect color. And finally, using two eyes allows the brain to perceive near-stereoscopic images.

A bit of history

Denkmeier Optical has produced fine binoviewers since 2001. Company founder Russ Lederman designed his initial binoviewer based on those he used with microscopes. He noted, however, that the optical configuration afforded an "extra" magnification around 3.5x, whereas the ones in microscopes added none.

Such a system-wide power increase was great for the planets but not for deep-sky objects. This led Lederman to different innovations, such as a lower-magnification (1.3x) compound optical system.

For the Binotron-27, Denkmeier literally went back to the drawing board and came up with an all-new design. Engineers were able to incorporate several refinements to earlier binoviewer designs that make this model user friendly while still affording spectacular views. For a start, the Binotron-27 incorporates prisms 27 millimeters across, which affords each a 26mm-wide clear aperture.

PRODUCT INFORMATION

Denkmeier Binotron-27

Includes: Power x Switch system with all spacer tubes, aluminum caps and eyepiece holder plugs, aluminum case

Optional: 21mm D21 eyepieces ($549/pair); 14mm D14 eyepieces ($629/pair); Filter Switch ($249); OCS-A45($149)

Price: $1,099; $1,399 (SCTs and refractors)

Contact:

Denkmeier Optical
135 Marcus Blvd.
Hauppauge, NY 11788-3702
[t] 866.340.4578
[w] www.deepskybinoviewer.com

Features

The Denkmeier Binotron-27 comes packaged in an aluminum case with custom foam inserts. The one I reviewed included all of the adapters, a pair of 21mm eyepieces designed specifically for this instrument, and various end caps. This set also had the company's Power x Switch system (which allows three magnifications with a single set of eyepieces) and the optional OCS-A45 optical corrector.

The first thing that struck me as I took the Binotron-27 out of the case was the high quality of the machine work and construction. This binoviewer looked and felt like top-notch gear. The important hinged interpupillary

Denkmeier Optical's Binotron-27 is a high-quality binoviewer. The two push/pull levers on the unit shown here operate the included Power x Switch system. ALL IMAGES: *ASTRONOMY*: WILLIAM ZUBACK

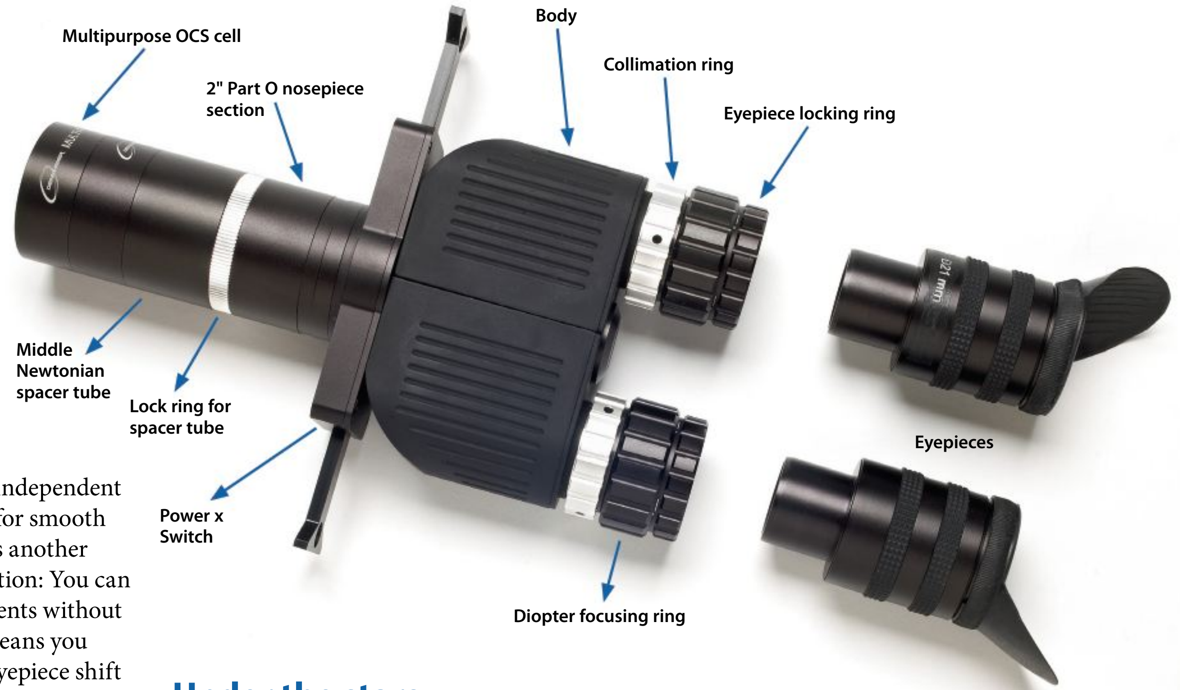
Mike Reynolds *is an* Astronomy *contributing editor and dean of Liberal Arts and Sciences at Florida State College at Jacksonville.*

distance adjustment — which allows observers to match the distance between their eyes — was smooth, yet stiff enough to stay in place once adjusted.

The Binotron-27 also has a lightweight rubber coating, which allows for a solid yet comfortable grip. Even the fully machined end caps display another example of excellent design.

The two eyepieces feature independent diopter adjustment, allowing for smooth individual focusing. But here's another important Denkmeier innovation: You can fine-tune the diopter adjustments without the eyepieces rotating. This means you won't experience any sort of eyepiece shift during focusing after you lock the eyepieces into place. And on that last note, the eyepieces of the Binotron-27 lock securely into place without thumbscrews.

A major innovation that Denkmeier has incorporated into its new binoviewer is the ability to quickly collimate the Binotron-27. And you can do this without the need for tools — or a telescope! I know how easily a binoviewer can lose its collimation, having used mine for many years with college classes and for outreach. Each time, that meant sending it back to the manufacturer. Not anymore.



Denkmeier supplies all the parts (eyepieces optional) that you'll need to use the Binotron-27 with your telescope.

Under the stars

I found that the optics Denkmeier put in the Binotron-27 performed superbly. I observed with the device connected to several different telescopes and viewed a number of celestial objects through each. I like first to test optics on a bright Moon, so I observed our satellite when it was nearly Full. With that much light passing through the unit, optical flaws, especially those related to color, are easy for me to see. In this unit, however, I detected none. And the Moon took on a near-3-D appearance, which seemed to get better the longer I observed.

I also made a visual survey through the Binotron-27 of several objects: Comet PANSTARRS (C/2011 L4), Saturn, and the Orion Nebula (M42). To say that Saturn was incredible would be an understatement — it appeared to be three-dimensional to me. I have viewed Saturn through my own binoviewer many times before, but this image was much sharper.

Jupiter and the four Galilean satellites also were a treat. Using the Power x Switch, I was able to select any of three magnifications. This option allowed me to easily view at different powers and glean what was best for each object considering the night's seeing (steadiness of the air).

The Binotron-27 comes with a sturdy, foam-lined aluminum carry case. Although the case measures a slim 14 by 11 by 5 inches (35.6 by 27.9 by 12.7 centimeters), it has enough room for a set of custom-made Denkmeier eyepieces.

One of the tests I like performing on optics is simply to note how bright stars appear. I observed numerous stellar standouts with different brightnesses and colors. I could see no optical flaws in the system regardless of which scope I used.

I also observed a number of deep-sky objects. Open clusters included the Double Cluster (NGC 869 and NGC 884) in Perseus and the Pleiades (M45). I marveled at how stars appeared as pinpoints right to the edge of the field of view while the background appeared like black velvet.

I hopped through a selection of bright galaxies in Ursa Major and Leo, and visited a variety of planetary and other nebulae. All views proved excellent. I didn't get the three-dimensional feel with deep-sky treats like I did with Saturn, but that could be due to the faintness of the objects or the age of my eyes. I choose the former reason!

You know you want one

Denkmeier has designed and produced a remarkable binoviewer, well worth the investment. Whether you are a deep-sky visual observer who uses a big Dobsonian-mounted reflector, a planetary observer with an apochromatic refractor, or just a person with the passion to share the universe with others, the Binotron-27 will certainly take your observational sessions to a whole new level. Two eyes and the Denkmeier Binotron-27 are certainly better than one eye at the telescope.

COSMIC**IMAGING**

BY TONY HALLAS

The *RegiStar* connection

Great software and a new technique will simplify your processing.

In last month's article, I presented the concept of batch-processing camera RAW files to enable the creation of a massive signal-to-noise ratio. In this article, I will assume that you have dithered all your images and have processed and saved all your files to a folder. Note that you should have saved your files in 16-bit TIFF format.

Let's assume you have 28 processed files you want to combine into a single file. First, make four folders and put seven files in each one. Next, open *RegiStar*. If you find the "Groups Manager" annoying, you can close it by clicking "Options," then "Hide Groups Manager," and it disappears. Go to "File," then "Open," and select an image from your first folder. You do not have to open all the images. Under "Operations," click on "Register" (or use the shortcut F2).

"Multiple Source" should be the only choice, and at this point the software will prompt you to choose a folder. It should have already selected the one you chose your file from, but if not, you can browse to it and select it. Then simply click "Register," and go get a snack. *RegiStar* will now open and align every one of your images in the folder to the one you chose initially.

If you notice that *RegiStar* is having a hard time aligning the images because you have very noisy ones, go to "Noise Compensation" and try "Level 1" or "Level 2." When it finishes, go once again to "Operations" and choose "Combine" (or press the shortcut F4).

At the bottom of the page, click "Select All Images." In the "Function to Apply" window, choose "Median/Mean." This is a special combine algorithm that averages all your images while at the same time rejecting any outliers like satellite trails. Leave everything else at the default settings, and click "OK."

RegiStar now will average all your aligned images and reject any spurious data. You will notice immediately how much smoother the result is compared to a single image. Save this combined image into the same folder the TIFF files came from.

Now go back and repeat this process for the other three folders. You might wonder, "Why not do all of them at once?" It's because your computer probably doesn't have enough memory to handle so much data at once.

When you have created all four master files, open them in *RegiStar*, align them, and then simply average them together. Since you already have rejected all the outliers, all you need is a simple average to increase the signal-to-noise ratio even further. Save this result as the "Master Combine File."

Close *RegiStar* and open the file in *Photoshop* to make any further enhancements you desire. The final result will be stunning, and most of the grunt work will have been done automatically once you initiate the processing. I found this technique so useful that I'm creating a new DVD that soon will illustrate this entire process in greater detail.

Happy shooting!

This "before and after" pair of images illustrates the author's new technique. The left image is a single file showing a satellite trail. After using *RegiStar* in the way he describes, the author created the image at right. TONY HALLAS

FROM OUR INBOX

Rainbow phenomena

I just read Stephen James O'Meara's column "Rare rainbow phenomena" in the June 2013 *Astronomy*. I've included a picture I took about seven years ago in Santa Fe, New Mexico, which shows a double rainbow and Alexander's Dark Band.

This is why I love reading your articles: They make me discover things I didn't even know I had observed at the time.
— Michael Cefola, Sante Fe, New Mexico

On May 8, I took this picture of a double rainbow with spokes. I knew I had seen this phenomenon earlier, and now I remember where: in the June 2013 *Astronomy*! Clear skies. **— Bruno Billiaert,** Duffel, Belgium

Corrections

In the "Rockets rocked it" story (p. 12) of the August 2013 issue, SpaceX should be Virgin Galactic.

The declination lines in "40 deep-sky targets in Sagittarius" (p. 70) of the same issue were labeled incorrectly. Subscribers can download the corrected version of the article online at www.Astronomy.com/40sagittarius. We apologize for the errors and inconvenience. **— *Astronomy* Editors**

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Imaging guide

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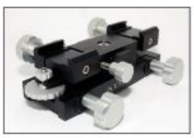

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Matrix's Easy Up Dolly attaches to a telescope tripod and allows easy moving of the assembly. Once it's in place, you can extend the tripod's legs to the ground without having to remove it from the dolly. Wheel sizes range from 2.5 to 10 inches (6.4 to 25.4 centimeters).

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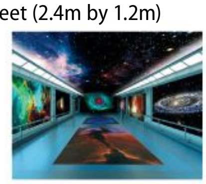

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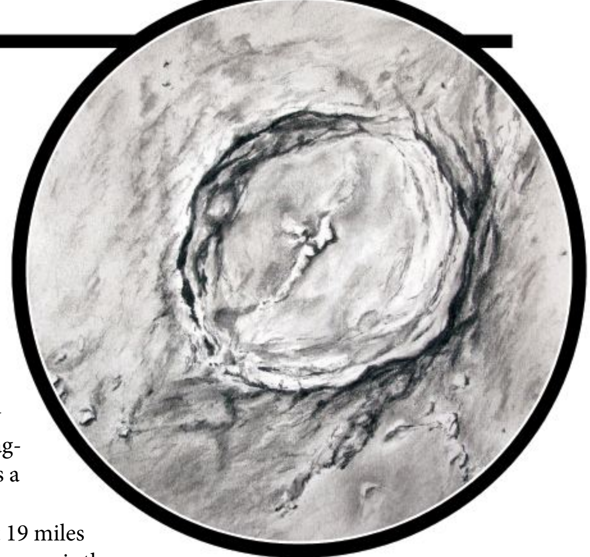
ASTRO**SKETCHING**

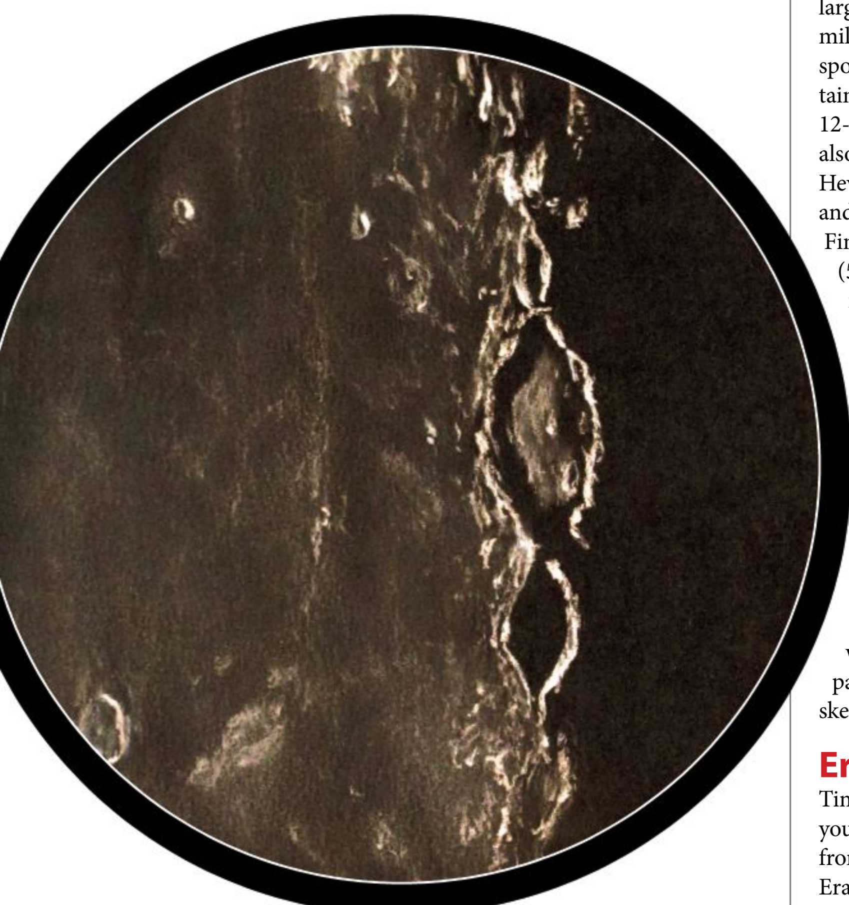
BY ERIKA RIX

Our amazing Moon



For this sketch of the crater Eratosthenes, the author used a 16-inch f/4.5 reflector on a nontracking Dobsonian mount and an eyepiece that gave a magnification of 257x. She made this sketch October 7, 2011, between 1h05m UT and 3h30m UT. Her materials were Rite in the Rain paper and charcoal.

The lunar terminator, the dividing line between the Moon's sunlit and dark portions, provides stunning views, yet it can be challenging to sketch. As sunlight advances (during the Moon's waxing phases) or retreats (during the waning phases), shadows along the terminator move swiftly. To capture the view quickly, I have found that drawing highlights is easier than capturing shadows. The following description of the sketch I made of three craters along the terminator illustrates what I mean.



The author sketched the craters Hevelius, Lohrmann, and Cavalerius on January 7, 2012, between 2h00m UT and 3h40m UT. She observed through a 16-inch f/4.5 reflector on a nontracking Dobsonian mount. Her eyepiece gave a magnification of 225x, and she used a Moon filter. Her sketch was on black Strathmore Artagain paper using a white Conté crayon, a pastel pencil, and a charcoal pencil. ALL SKETCHES: ERIKA RIX

Hevelius, Lohrmann, and Cavalerius

Located on the western edge of Oceanus Procellarum, this trio of craters makes a striking chain one day before Full Moon or two days before New Moon. Lohrmann and Hevelius both are from the Nectarian geological period (3.92 to 3.85 billion years ago) while Cavalerius formed during the Eratosthenian period (3.2 to 1.1 billion years ago). Nearby attractions include the lunar basin Grimaldi just south of Lohrmann, the landing sites of Moon probes Luna 8 and 9 northeast of Cavalerius, and Reiner Gamma, an area of highly concentrated magnetism known as a "bright swirl."

Lohrmann, at 19 miles (31 kilometers) across, is the smallest of the three. You can observe it, however, through a 4-inch telescope using moderate magnification. Hevelius is the largest with a diameter of 66 miles (106km), so it's easy to spot the crater's central mountain and craterlets. If you use a 12-inch scope at 225x, you'll also be able to observe Rimae Hevelius, a rille system within and to the south of this crater. Finally, Cavalerius is 36 miles (58km) wide with steep terraced walls, a flat floor, and a small central mountain.

To sketch these three craters, focus on rendering highlights along the terminator first and then work outward. Shadows will evolve naturally in your drawing, although you can use a charcoal pencil to accentuate them if needed. You'll need a white pastel pencil and black paper for this white-on-black sketching technique.

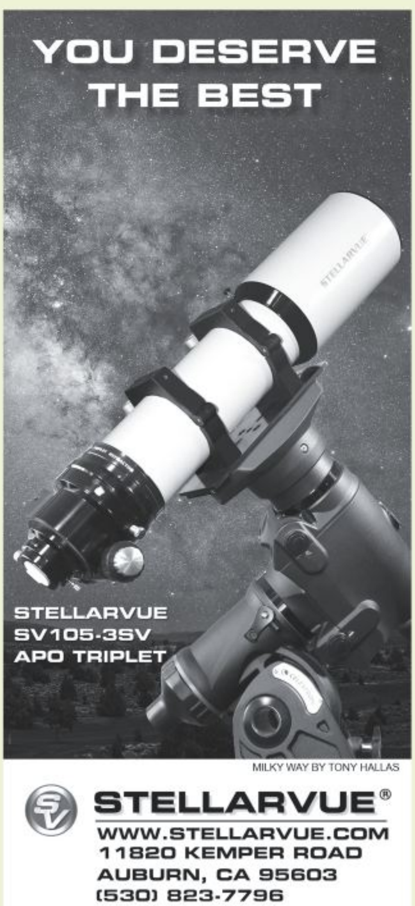
Eratosthenes

Time is less of a concern when you're sketching features far from the terminator. Let's use Eratosthenes Crater as an example. This feature measures 37 miles (60km) across and nestles in the lower arm of Montes Apenninus on the northern edge of Sinus Aestuum. It has a distinct mountain range to the southwest.

Eratosthenes, not surprisingly, formed during the Eratosthenian period when low-lying areas flooded with lava. It appears best one day after either First Quarter or Last Quarter. Pretty much any size telescope will do. As you observe it, increase the magnification to enjoy the details within its tormented walls and elongated central mountain.

The rich tonal range of charcoal on white paper is perfect for detailed sunlit areas, such as the terraced walls of such a complex crater as Eratosthenes. This black-on-white technique is different because you sketch the crater outline and shadows first, followed by the surrounding terrain. Highlighted areas remain untouched.

The Moon has more visible features than any other celestial object. So it's only fitting, I suppose, that observers have developed several ways to observe — and sketch — its varied terrain. Good luck!



INDEX *of* ADVERTISERS

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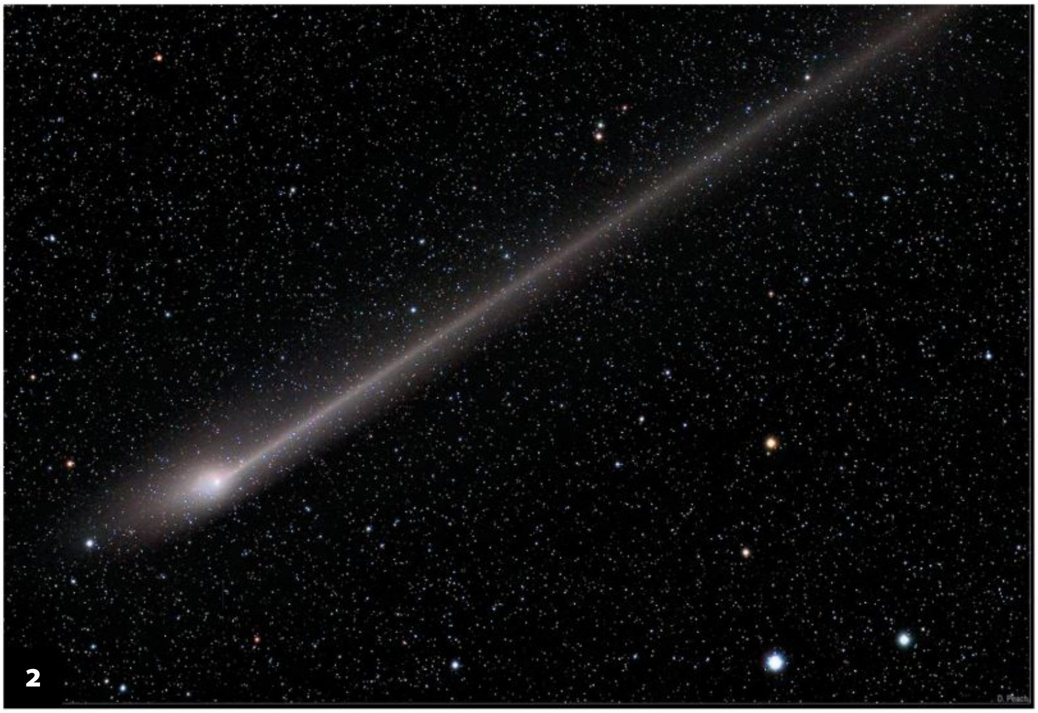
READER GALLERY

1. THE "SUPER" MOON
The nearest Full Moon of 2013 rises above the Chapel of Nossa Senhora do Castelo in Mangualde, Portugal. The building stands on the spot where King Sancho I built a Romanesque chapel in the early 13th century. The imager set up 1¼ miles (2 kilometers) from the chapel. (3.2-inch Astro-Professional refractor at f/7, Canon 50D DSLR, ISO 640, 1⁄80-second exposure, taken June 23, 2013, at 9:22 P.M. local time, from Mangualde, Portugal) • ***Miguel Claro***



2. STILL GOING STRONG
Comet PANSTARRS (C/2011 L4) still appeared impressive more than two months after its perihelion March 10. This image captures it within the constellation Draco the Dragon glowing with a total magnitude of 9.4. (4-inch Takahashi FSQ-106 refractor, STL-11000M CCD camera, LRGB image with exposures of 12, 2, 2, and 2 minutes, respectively, taken May 30, 2013, at 4h57m UT) • ***Damian Peach***

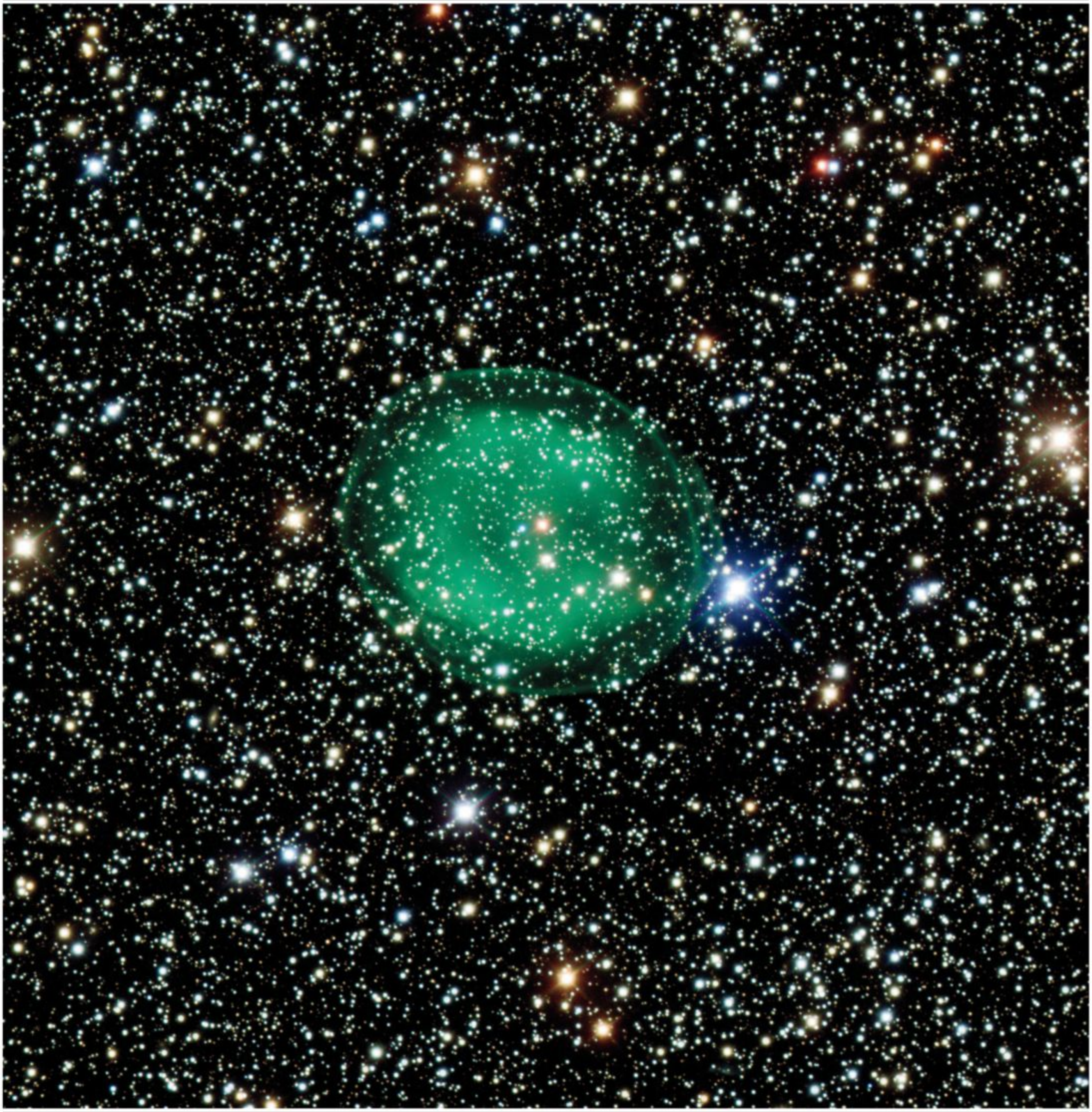
3. THE CELESTIAL SNOW ANGEL
Sharpless 2–106, also known as vdB 133 and LBN 219, is a nebula surrounding and lit by the magnitude 6.2 star 44 Cygni. The object combines a small blue reflection nebula and a large red emission nebula. It lies approximately 1,600 light-years from Earth. (8-inch Officina Stellare Riccardi-Honders Veloce RH 200 OTA reflector, SBIG ST-8300M CCD camera, LRGB image with exposures of 180, 140, 120, and 160 minutes, respectively) ***• Harel Boren***

4. THE RING NEBULA
M57 is one of the sky's most famous objects. These two imagers combined data collected over 14 nights, including six 1-hour Hydrogen-alpha exposures, which helped show the nebula's dim outer shell. (Two 12-inch Astro-Tech Ritchey-Chrétien astrographs, QHYCCD QHY9 and SBIG STT-8300 CCD cameras, 25 hours total exposure time) ***• Terry Hancock and Fred Herrmann***

5. STAR SYSTEMS IN THE DUST
Spiral galaxy NGC 7753 and its companion, the barred lenticular galaxy NGC 7752 below it, lie approximately 270 million light-years away. Both float through space in the constellation Pegasus the Winged Horse. Amateur astronomers often compare them to another galactic pair, the Whirlpool Galaxy (M51) and its companion, NGC 5195. (32-inch Schulman Telescope by RC Optical Systems, SBIG STX-16803 CCD camera, LRGB image with exposures of 8, 2, 2, and 2 hours, respectively) ***• Adam Block/Mount Lemmon SkyCenter/ University of Arizona***

6. MOUNTAIN MOONRISE
This stack of seven images shows the perigee (closest to Earth) Full Moon of 2013 rising in deepening twilight above the Santa Rita Mountains in south-central Arizona. The imager spaced his exposures four minutes apart. (Nikon D-300 DSLR mounted on a tripod, 135mm lens at f/16, ISO 400, 1/250-second exposures, taken June 22, 2013, from Green Valley, Arizona) ***• Burley Packwood***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.



ESO

Forecasting the solar system's fate

Astronomers know that some 5 billion years from now, the Sun will stop its nuclear fusion as it runs out of fuel and transforms into a red giant star. Swallowing up the inner planets, it will expand and then undergo a series of "burps" of gas, creating a glowing planetary nebula. The result could closely resemble the nebula shown here, IC 1295 in the constellation Scutum.

The green color of the nebula results from ionized oxygen, and the multiple shells that form a cocoon of sorts occur because bursts of gas first come off the dying star (the dim bluish sun at center) at low speeds and then high-velocity bursts ram into the older gas, creating a shock front. Alas, no one will be around on Earth to see our own planetary nebula, as the Sun will warm our planet to the point of boiling away the oceans in something like 1 billion years from now.

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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

December 2013: Venus shines brightest

As the sky starts to darken on these December evenings, a brilliant point of light stands out in the west. **Venus** has been adorning the evening sky for several months now, but it has never looked this bright. Earth's neighbor reaches greatest brilliancy on the 6th, when it shines at magnitude –4.9.

Venus spends the month against the backdrop of Sagittarius the Archer, and the Sun encroaches on this constellation as the month progresses. The planet arrived at greatest eastern elongation in early November, when it was 47° from our star. On December 1, it still lies 43° from the Sun, but the separation drops to 18° by month's end. You probably won't be able to follow the planet after New Year's Eve.

December marks the pinnacle for observing Venus through a telescope. As the planet draws toward the Sun, it gets closer to Earth and its disk grows dramatically. At the same time, Venus' sunlit hemisphere increasingly turns away from us, so we see the phase dwindle. On the 1st, the planet's disk appears 37" across and 31 percent lit. By the 31st, Venus spans 59" and shows a 5-percent-lit phase.

Once Venus sets in the west, **Jupiter** pokes above the eastern horizon. By late evening, the giant planet dominates the sky from its perch in the northeast. Jupiter decorates the distinctive constellation Gemini the Twins. As this region climbs higher in the sky, the planet appears above the Twins' two brightest stars, Castor and Pollux.

Although Jupiter doesn't reach opposition and peak visibility until early January, the view this month hardly suffers. The planet remains fairly far to the north, however, so Southern Hemisphere observers need to wait until midnight or later to get good views through a telescope.

Its higher altitude then increases the chances of experiencing those brief moments of good seeing when the image in the eyepiece steadies and the planet comes into sharp focus. Any telescope will show at least two dark atmospheric belts on Jupiter's 46"-diameter disk, while larger instruments reveal more detail. And the planet's four bright moons — Io, Europa, Ganymede, and Callisto — always put on an impressive show with their motion from night to night.

This month's two other bright planets don't appear until well past midnight. **Mars** rises some four hours before the Sun at the start of December and earlier still with each passing week. The Red Planet wanders eastward in Virgo, ending the month near the 3rd-magnitude double star Gamma (γ) Virginis.

Although Mars has been a fixture in the morning sky for many months, it still lies far from Earth. Even at the end of the year, the planet's light must traverse more than 200 million kilometers to reach us. Because of this distance, it shines unexceptionally at magnitude 0.9 and appears only 6.8" across through a telescope. The ruddy world will grow significantly brighter and bigger by the time it reaches opposition in early March.

Saturn appears low in the east during morning twilight in early December but climbs higher and into a darker sky by month's end. The ringed planet lies near the middle of Libra the Balance, to the upper left of Scorpius the Scorpion's head. At magnitude 0.6, however, Saturn shines conspicuously brighter than any of Libra's stars and even beats Scorpius' luminary, the 1st-magnitude red supergiant star Antares.

Particularly in late December, the gas-giant planet climbs high enough before dawn to make it a worthwhile target through a telescope. You'll see a 16"-diameter disk encircled by a ring system that spans 36" and tilts 22° to our line of sight. The New Year will bring better conditions for observing Saturn.

The starry sky

A lot of people don't know that the stars that dominate the night sky are intrinsically much brighter than the Sun. The brightness we see depends both on the amount of light a star emits and how far away it is. The Sun, for example, appears extraordinarily bright almost entirely because it lies so close. If you could view it from a standard distance of 10 parsecs (32.6 light-years), it would have a so-called absolute magnitude of 4.8. The four anchor stars of Crux the Southern Cross lie much farther away than this standard distance. Even the quartet's closest member, Gamma Crucis, shines across some 88 light-years.

After darkness falls in December, the night sky's two brightest stars gleam conspicuously. Sirius and Canopus, which appear toward the east and southeast, respectively, make interesting comparison objects with the Sun. Sirius is one of the nearest stars beyond the solar system and also radiates about 20 times more light than our Sun. This combination means Sirius shines at magnitude –1.4, brighter than any star in our sky besides the Sun.

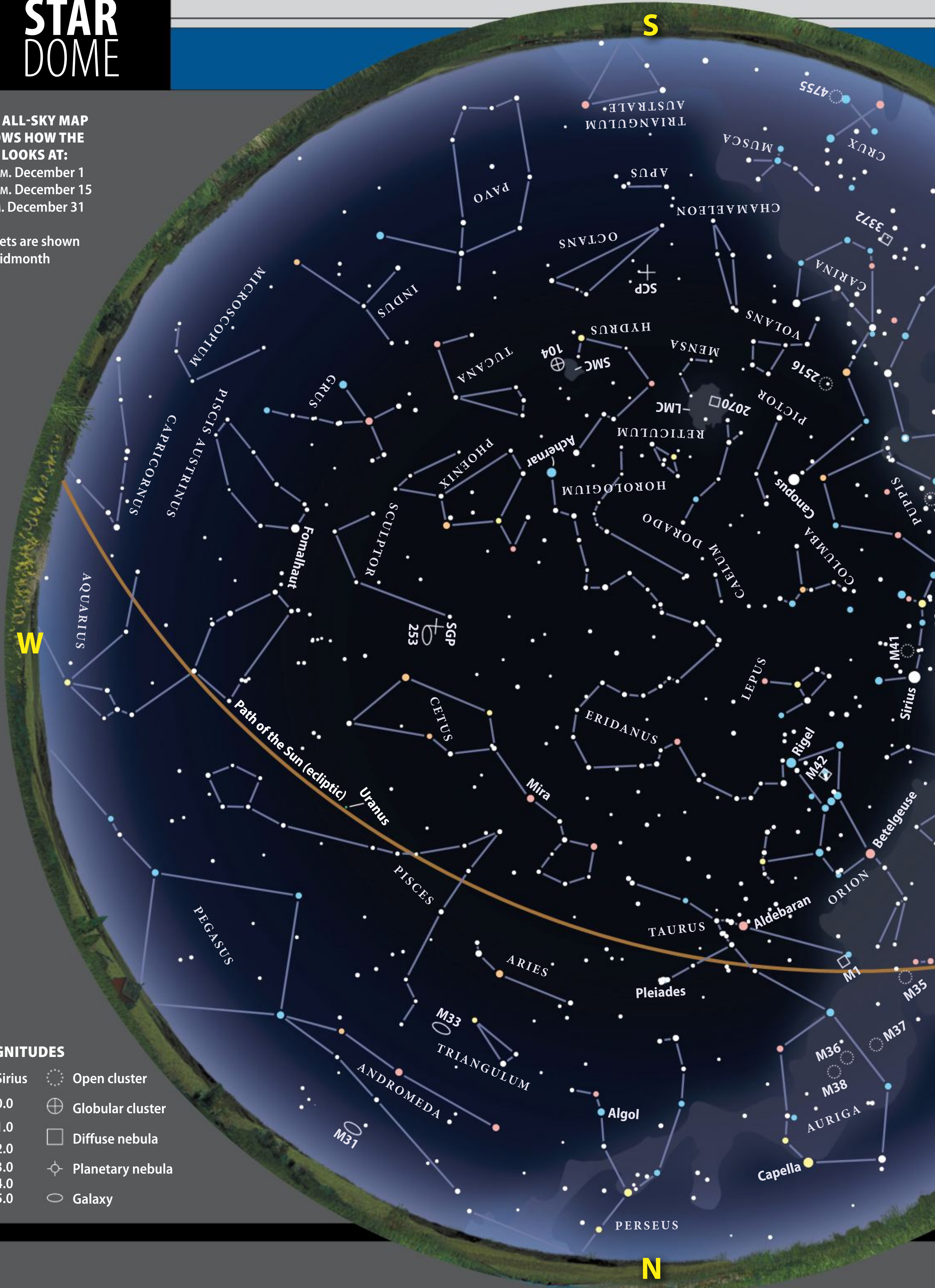
If the Sun were 8.6 light-years away like Sirius, it would shine only at magnitude 1.9, about midway in brightness between the western two stars in Orion's Belt.

If we turn our attention to Canopus, to the upper right of Sirius, we are gazing at a star some 310 light-years away that nevertheless rivals Sirius' brightness. At that distance, the Sun would shine at magnitude 9.6, close to the limiting magnitude through 7x50 binoculars under excellent conditions. Sweep along the Milky Way from Canopus to the Southern Cross with binoculars and consider that the Sun, if it were as far away as Canopus, would be about the same brightness as the faintest stars you see.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
11 P.M. December 1
10 P.M. December 15
9 P.M. December 31

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

DECEMBER 2013

Calendar of events

1 The Moon passes 1.3° south of Saturn, 10h UT

3 New Moon occurs at 0h22m UT

4 The Moon is at perigee (360,067 kilometers from Earth), 10h09m UT

6 The Moon passes 8° north of Venus, 0h UT

Venus is at greatest brilliancy (magnitude –4.9), 19h UT

8 The Moon passes 6° north of Neptune, 17h UT

9 First Quarter Moon occurs at 15h12m UT

11 The Moon passes 3° north of Uranus, 7h UT

14 Geminid meteor shower peaks

17 Full Moon occurs at 9h28m UT

18 Uranus is stationary, 2h UT

19 The Moon passes 5° south of Jupiter, 7h UT

The Moon is at apogee (406,269 kilometers from Earth), 23h48m UT

20 Venus is stationary, 20h UT

21 December solstice occurs at 17h11m UT

24 Asteroid Herculina is at opposition, 7h UT

25 Last Quarter Moon occurs at 13h48m UT

26 The Moon passes 5° south of Mars, 3h UT

27 The Moon passes 1.1° north of Spica, 3h UT

29 The Moon passes 0.9° south of Saturn, 1h UT

Mercury is in superior conjunction, 6h UT